Wastewater Management Through Effective Water Reclamation and Discharge Allocation

Oxford Wastewater Treatment Plant
Granville County, NC

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EXECUTIVE SUMMARY

Based on this study's analysis of the Oxford, North Carolina, wastewater treatment plant (WWTP) water quality data available for the years 2012-2014, the water quality of Oxford's WWTP effluent was excellent compared to the National Pollutant Discharge Elimination System (NPDES) permit standards. However, despite a high frequency of compliance with the NPDES permit standards over a three year period, zinc and oxygen concentrations in the WWTP effluent may be of concern for the Fishing Creek ecosystem downstream of the WWTP outfall especially during summer or dry periods. Without accurate Fishing Creek discharge data, the degree of dilution and therefore compliance with North Carolina Department of Environmental and Natural Resources (NC DENR) freshwater aquatic life standards for dissolved oxygen and zinc is unknown.

Based on the model results and subsequent analysis contained in this report, if the City of Oxford, North Carolina, builds a reclaimed water system, we recommend a wastewater discharge management plan which maximizes the amount of reclaimed water used for beneficial purposes from the City WWTP effluent discharge, with the remainder entering Fishing Creek. The projected amount of water to be reclaimed is estimated through four scenarios which are the inputs to two different models: the amount of reclaimed water is evaluated in economic terms through an incremental cash flow model; the in-stream environmental impacts of the allocation between reclaimed water and creek discharge are also evaluated using a Bayesian network model related to in-stream zinc and dissolved oxygen concentrations.

Maximizing the amount of reclaimed water used increases the economic benefit and probability of the Fishing Creek ecosystem being in a 'good' state as defined by the NC DENR metrics of the North Carolina Index of Biotic Integrity (fish assessment) and the bioclassification of macroinvertebrates in both wet and dry periods based on WWTP effluent discharge, zinc, and dissolved oxygen concentrations. Before a reclaimed water system is constructed, we recommend the City of Oxford and Granville County conduct a more in depth market study of potential reclaimed water users and demand. A more in depth study would make for better estimations of reclaimed water demand and in turn the economic and environmental benefits.

Keywords: water reclamation, wastewater, Bayesian network model, incremental cash flow model, project evaluation, zinc, dissolved oxygen

INTRODUCTION

Municipal wastewater treatment plants (WWTPs) are located in or nearby almost all urban and suburban settings in the United States. In 1996, there were slightly less than 20,000 WWTPs in the USA and approximately 75% of the population is served by municipal WWTPs (Laws, 2000; NAS, 1996). WWTPs commonly discharge into urban streams where they augment stream baseflow, and it is not uncommon for WWTP discharges to constitute a large percentage of urban stream flow (Paul & Meyer, 2001). In some cases, WWTP discharge can make up a majority of urban stream flow on an annual basis and even up to 100% of flow at certain times (Dennehy et al., 1998).

The ecological effects of WWTP effluent discharge on urban streams are broad and well-studied. In general, modern secondary or tertiary treatment WWTP discharges in urban streams cause eutrophication and low in-stream nutrient retention efficiencies (Marti et al., 2004; Laws, 2000). WWTP discharge also increases pollutants such as organic carbon, nitrogen, and phosphorous, which reduces in-stream invertebrate diversity (Paul & Meyer, 2001). Similarly, Gucker et al. (2006) found present day WWTP discharges caused 'extensive' effects on stream ecosystem structure and function by increasing whole-stream community respiration and gross primary production. Gucker et al. also found increases in the macrophytes and benthic invertebrate biomass. In addition, WWTP effluent is known to negatively affect fish diversity and abundance (Harkness, 1982).

This study examines the management of the City of Oxford, North Carolina, WWTP effluent discharge into Fishing Creek, a stream with partial urban and rural watershed characteristics. The City of Oxford, North Carolina, is located in the Piedmont region of the eastern United States and is found within Granville County, Figure 1. The City's WWTP is located south of Oxford between Highway 96 and Interstate 85 off NCSR 1649/New Commerce Road on Community Drive. The WWTP discharge pipe or outfall (identified as outfall # 001 on the WWTP's National Pollutant Discharge Elimination System (NPDES) permit) is located at the confluence of Fishing Creek and the Foundry Branch, a smaller tributary of Fishing Creek. Fishing Creek is a tributary of the Tar River which flows to Tar-Pamlico Sound and eventually to the Atlantic Ocean.

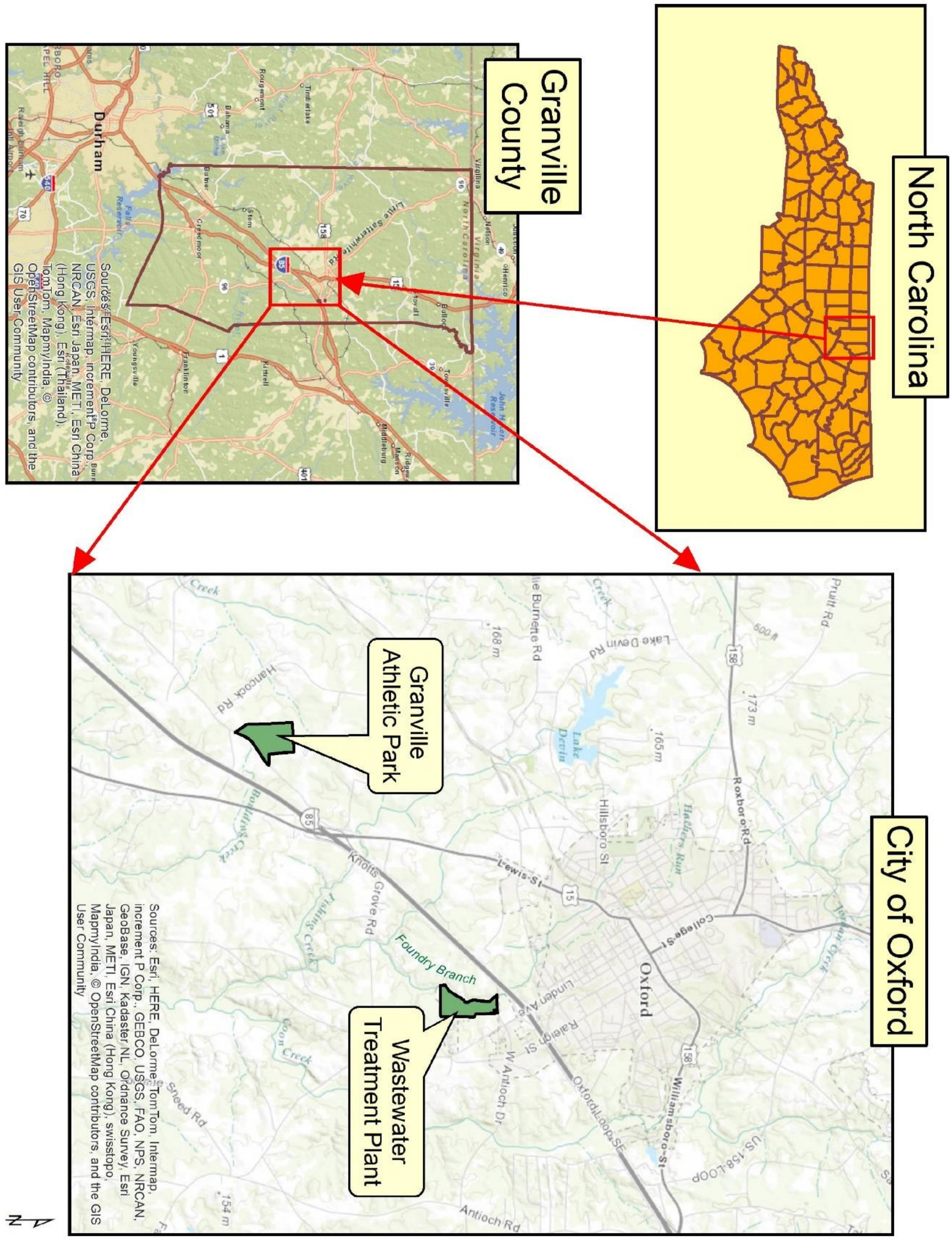


Figure 1: Geographic location of the Granville Athletic Park and Wastewater Treatment Plant within Oxford, Granville County, North Carolina.

Fishing Creek downstream of the Oxford WWTP outfall is currently on the North Carolina Category 5 303(d) impaired list and has been since 1998 due to low ecological/biological integrity of the stream's benthic community (NC DENR, 2014). The 303 (d) classification is reported to the Environmental Protection Agency (EPA) every two years and represents waters that are most threatened or impaired by water quality. In 2006, a North Carolina Division of Water Quality (NC DWQ) monitoring effort confirmed the 303(d) listing status by finding stressed fish and macroinvertebrate communities downstream of the WWTP outfall (NCDWQ, 2007). Also in 2006, benthic invertebrate communities were found to improve approximately 4 miles downstream of the outfall (W. K. Dickson & Co., Inc., 2012). The 2006 monitoring effort also found elevated conductance, high fecal coliform bacterial levels, a more basic pH than upstream, increased turbidity, high zinc and copper concentrations, and high total Kjeldahl Nitrogen just downstream of the WWTP outfall.

Since its construction, the WWTP has been upgraded several times. The plant was expanded in 1989 to be able to treat a maximum of 2.17 million gallons per day (MGD). The final and latest WWTP upgrade occurred in 2006 just after the NC DWQ 2006 Fishing Creek monitoring effort. This upgrade added a tertiary sand filter, ultra violet disinfection, and increased the plant's capacity to 3.5 MGD (Adams Robinson, 2015). Prior to the UV disinfection system the WWTP utilized chlorine for sanitary sewage effluent disinfection.

The quality of the effluent since the WWTP upgrade is thought to have improved. In addition, at site SR 1643, approximately 6 miles downstream of the WWTP outfall, the NC DENR found the North Carolina Index of Biotic Integrity (NCIBI), which measures fish community health, before the upgrade to be good/good-fair in 1992,1997, and 2002 and to be excellent after the upgrade in 2006 and 2012. However, the change in the Fishing Creek ecosystem below the WTTP outfall due to the upgrade is largely unknown.

Since the mid-1970s, water from Kerr Lake, by way of an inter-basin transfer (IBT) agreement, is the source of potable water for Oxford. The Kerr Lake Regional Water System (KLRWS) sends treated, potable water to the Oxford where it is stored in two above ground tanks and distributed to users. This is the source of water that is eventually treated by Oxford's WWTP and discharged to Fishing Creek.

Kerr Lake is a dammed section of the Roanoke River located to the Northeast of Oxford (USACE, 2005). Kerr Lake itself straddles the border of Virginia and North Carolina, and the John H. Kerr Dam is located in Virginia. The dam was constructed in 1952 by the U.S. Army Corps of Engineers (USACE) (CH2M Hill, 2015). Originally, this USACE project was created for hydropower, recreation, flood control, and navigation purposes. The Water Supply Act of 1958 expanded upon the lake's functions to include municipal water supply (CH2M Hill, 2015).

Currently, several municipalities and organizations have water supply agreements with USACE to use water from Kerr Lake. These include: Town of Clarksville, VA; City of Virgnia Beach, VA; VA Department of Corrections; Mecklenburg Co-Generation Limited

Partnership, VA; Burlington Industries (no longer in operation); and the Kerr Lake Regional Water Supply System (KLRWS). The KLRWS serves three bulk water customers or "partners": the City of Henderson, the City of Oxford, and Warren County, NC. The KLRWS is made up of a treatment plant, distribution mains, and storage tanks for the purpose of creating potable drinking water (City of Henderson, 2013). The City of Oxford as a 'partner' receives approximately 20% of the KLRWS output (CH2M Hill, 2015).

In 2003, the KLRWS water treatment plant located in Henderson, NC, experienced high water demands that were 80% of its 10 million gallons per day (MGD) capacity on multiple occasions (CH2M Hill, 2015). Accordingly, the KLRWS, in planning for future water demand, was awarded a reallocation of 10,292 acre-feet (AF) from the USACE Kerr Lake conservation pool in 2005 which increased KLRWS total and current allocation to 21,115 AF (USACE, 2005). This reallocation also converts an original 'water use' agreement to a 'storage agreement.' The allocation is equivalent to a demand of 20 MGD which is the amount that EE&T, in 2003, projected the KLRWS water demand to be in 2034.

KLRWS is also planning a 20 MGD expansion of its water treatment plant. According to a 2015 projection by CH2M Hill (2015), the 20 MGD will be adequate to meet KLRWS water demand through 2045. However, increased water usage for the KLRWS would also require an increased IBT capacity compliant with North Carolina state law since much of the KLRWS water usage transports Kerr Lake water out of the Roanoke River Basin (NC Administrative Code, Inter Basin). The current "grandfathered" IBT amount for KLWRS is 10 MGD, which is a daily maximum. The amount KLRWS is requesting as a new IBT is 14.2 MGD and is measured as the maximum average day IBT as compared to all months in a calendar year. If the IBT transfer request, *pending with the NC Environmental Management Commission,* is approved and the permitted water treatment plant expansion, *not yet initiated*, is completed, the KLWRS will have the allotted amount of water and the capacity to deliver up to 20 MGD.

Despite the likelihood of a guaranteed 20 MGD water supply, the KLWRS could still encounter water scarcity in its near future through the combination of demand and regional droughts. The lowest lake level elevation at Kerr Lake on record is 280.23 feet in 1956 (USACE, 2012). More recently during a 2013 drought, the lake level fell below 294 feet to 293.03, which triggered KLWRS voluntary water use restrictions with a water demand reduction goal of 5% for all KLRWS users, Table 1 (Ashley, 2013; KLWRS, 2011). In a 1992 drought contingency plan, the USACE stated that the recurrence interval of a drought that would cause the lake elevation to drop to 293 feet or below would be in excess of 100 years (USACE, 1992).

Table 1: Kerr Lake Regional Water System water shortage response declarations & restrictions based on Kerr Lake elevation (KLWRS, 2011)

Kerr Lake Elevation (at or below)	Declaration	Restrictions
294	Voluntary Water Use Restrictions	Water Demand Reduction Goal of 5%
289	Mandatory Conservation	Bans on ornamental or outdoor non-commercial uses; Water Demand Reduction Goal of 10%
284	Water Shortage Emergency	Bans on uses other than for sustaining human/pet life, sanitation, hygiene, firefighting, or system maintenance; Water Demand Reduction Goal of 40%
280	Rationing	Mandatory rationing of 50% or more

The State Climate Office of North Carolina states that historical analysis of drought severity and frequency show that between the years of 1997and 2007 North Carolina experienced 2 very severe drought events in 2002 and 2007 (Lamp, 2007). However, Patterson et al. (2010) found little evidence of drought frequency, severity, or magnitude becoming more severe in the 21st century in the U.S. South Atlantic region as measured by monthly streamflow falling below the 20th percentile over a three month period. Yet despite a lack in trend of drought characteristics, Patterson et al. found that average streamflow has decreased in the region. Decreased streamflow combined with increasing water demand exacerbates drought effects and could affect the recovery time of reservoirs and other sources from droughts.

In addition to the possibility of KLWRS experiencing water scarcity, Oxford may experience water stress in its long term future due to the limit of its allocation within the KLWRS. As mentioned earlier, Oxford has approximately a 20% stake in the KLWRS. As such it would be allotted 4 MGD out of the 20 MGD KLWRS allotment if the IBT Transfer is approved. The City of Oxford 2010 Water and Wastewater - 30 Year Master Plan projects Oxford's 2039 water demand to be approximately 5 MGD (West, 2010). This projection leaves Oxford with a 1 MGD deficit in 2039. However, a more recent 2015 projection done by CH2M Hill in the Environmental Assessment for the IBT application estimated that Oxford would not surpass an average demand of 4 MGD until approximately 2060 (CH2M Hill, 2015). The Oxford Water and Wastewater - 30 Year Master Plan does note that the City could purchase water from the other KLWRS partners if Oxford demand was greater than its supply (West, 2010). However, if Oxford and the KLWRS both experience water shortage it would likely be more difficult for Oxford to fulfill its water demand in this manner.

A viable alternative to securing new potable water supply sources for the City of Oxford, that is resilient to drought conditions, is water reclamation. A reclaimed water system generates and utilizes tertiary treated wastewater effluent that meets state standards for non-potable uses (NC Administrative Code, 2011). Reclaimed water usage conserves and reduces the use of water resources such as potable water, surface water, and groundwater. Reclaimed wastewater for irrigation and other uses is a common practice in Florida and California (EPA, 2012). In 2009, there were 36 existing municipal water reuse systems in North Carolina (Environmental Management Commission, 2009). In fact, in 2009, Granville County and Oxford contracted a 'Reclaimed Water System Study' to assess the feasibility of reclaiming Oxford WWTP effluent for the purpose of irrigating a county park, Granville Athletic Park at Jonesland Environmental Preserve (GAP), and to fulfill water usage at the WWTP, Figure 1 (Wightman, 2010). The hope is that reclaiming a portion of the Oxford WWTP's wastewater will be a source of income, a sustainable water source, and potentially a method to alleviate environmental stress on Fishing Creek due to WWTP effluent discharge.

The purpose of this study is 1) to determine quality of WWTP effluent and the need to manage its discharge to Fishing Creek and 2) to outline a wastewater discharge management plan for the City of Oxford that allocates treated effluent discharge to Fishing Creek and also to water reclamation for beneficial purposes. The amount of water to be reclaimed will be evaluated in economic terms through an incremental cash flow model from the perspective of Oxford. In addition, the amount of water to be discharged to Fishing Creek and/or reclaimed will be evaluated in terms of environmental impact using a Bayesian network model (BNM). Taken as a whole, this study will combine environmental effects and economic benefits of reclaiming treated effluent to determine an optimal effluent discharge plan between the options of reclaiming and discharging to Fishing Creek.

WWTP EFFLUENT WATER QUALITY & NPDES PERMIT STANDARDS

The NPDES is administered by the NC DENR and overseen by the U.S. EPA. The NPDES permit for the City's of Oxford's WWTP has several water quality standards that must be met before wastewater can be discharged to Fishing Creek, Table 2.

Table 2: City of Oxford wastewater treatment plant National Pollutant Discharge Elimination System (NPDES) permit water quality standards.

PARAMETER	SEASON	MONTHLY AVG	WEEKLY AVG	DAILY MAX
BOD, 5 day*	April 1st - Oc. 31st	5 mg/L	7.5 mg/L	-
BOD, 5 day*	Nov. 1st – March 31st	10 mg/L	25 mg/L	-
TSS**		30 mg/L	45 mg/L	-
NH_3	April 1st - Oc. 31st	1 mg/L	3 mg/L	-
NH_3	Nov. 1st – March 31st	2 mg/L	6 mg/L	-
Fecal Coliform***	-	200 / 100 mL	400 / 100 mL	-
pH	-	6-9	6-9	6-9
Cyanide	-	-	5 mg/L	22 mg/L
Mercury	-	-	.012 mg/L	.012 mg/L
Total Selenium	-	-	5 mg/L	56 mg/L
Dissolved Oxygen	-	5 mg/L	5 mg/L	5 mg/L

*5 day Biological Oxygen Demand at 20° Celsius

**Total Suspended Solids

*** Geometric Mean Values

WTTP water quality data from the years 2012, 2013, and 2014 were compared with the NPDES permit water quality standards. In the entire three year data-set, there were only three one-time water quality standard noncompliance instances: the monthly average Ammonia, the weekly cyanide, and the dissolved oxygen (DO) concentration standards. For the one-time noncompliance events the NH_3 standard was exceeded by approximately 0.5 mg/L, the cyanide standard by 2 mg/L, and the DO was under the standard by 0.6 mg/L . All water quality data, when less than laboratory equipment sensitivity, was assumed to be equal to the equipment sensitivity threshold which conservatively elevates much of the water quality data reported.

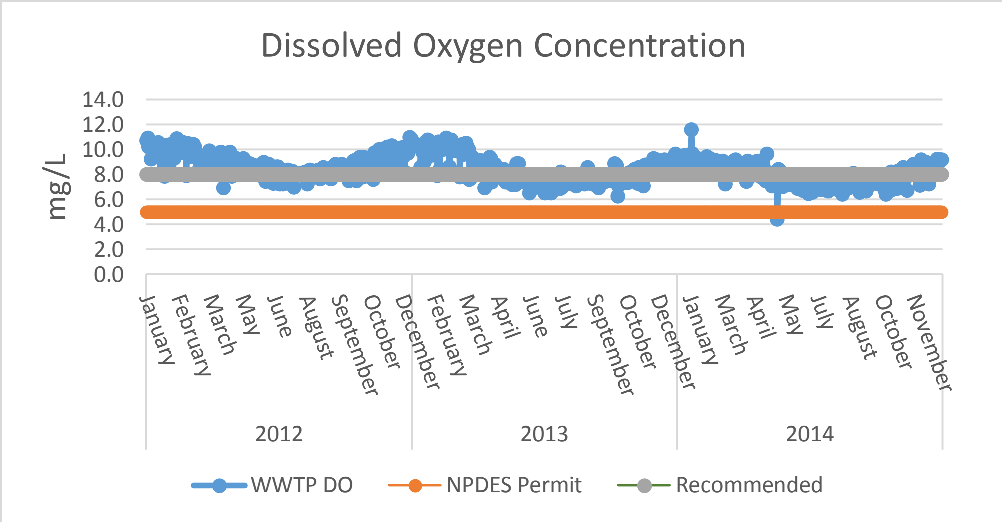


Figure 2: 2012-2014 dissolved oxygen (DO) concentrations in the City of Oxford's wastewater treatment plant effluent. National Pollutant Discharge Elimination System Permit standard and the North Carolina Department of Environment and Natural Resources freshwater aquatic life standard is 5 mg/L. The recommended concentration of 8 mg/L, to support most stream biota, is provided as a reference (Hinton & Voss, pers. comm. Table 19). To determine Fishing Creek DO freshwater aquatic life standard compliance, effluent concentrations and dilution in natural stream flow would have to be taken into account.

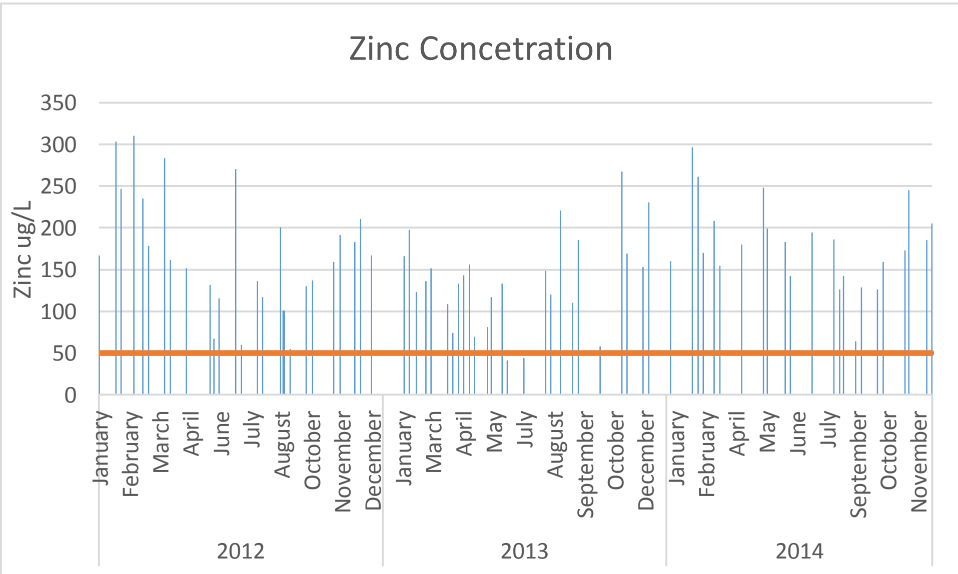


Figure 3: 2012-2014 zinc concentrations in the City of Oxford's wastewater treatment plant effluent. North Carolina Department of Environment and Natural Resources freshwater aquatic life standard for zinc is 50 ug/L. It is represented by the orange line and shown for reference (North Carolina Administrative Code, 2013). To determine Fishing Creek zinc freshwater aquatic life standard compliance, effluent concentrations and dilution in natural stream flow would have to be taken into account.

Figure 3 and Figure 2 visualize the concentration of zinc and DO in Oxford's WWTP effluent in ug/L. Zinc is not a pollutant with an accompanying standard within the WWTP's NPDES permit. However, zinc surface water concentrations are regulated in North Carolina by rules set forth in 15A NCAC 2B. The concentration for zinc in surface freshwaters for aquatic life is 50 ug/L (North Carolina Administrative Code, 2013). The ambient concentration of zinc and DO in Fishing Creek downstream of the WWTP outfall is unknown and is dependent on WWTP effluent concentrations and the degree of dilution from natural stream flow.

NORTH CAROLINA RECLAIMED WATER REGULATION

Water reclamation standards and practices are regulated at the state level. Federal regulations governing reclaimed water usage in the United States do not exist (NRC, 2012). However, recommended non-binding federal guidelines for water reclamation do exist. They are the *2012 Guidelines for Water Reuse*, created by the U.S. EPA (EPA, 2012). These guidelines are based in part on a review of state regulations (NRC, 2012).

In North Carolina, water reclamation is regulated by Title 15A, Subchapter 02U of the North Carolina Administrative Code; this state regulation was last updated in 2011 (NC Administrative Code, 2011). It is worth noting that neither the state regulations nor the EPA guidelines are based on rigorous risk assessment methodologies of human or environmental exposure to reclaimed water (NRC, 2012).

Under North Carolina law, a reclaimed water system can be either conjunctive or non-conjunctive. A conjunctive reclaimed water system is one where the option to reclaim water is not necessary for the wastewater disposal facility to meet its legal disposal requirements, for example a NPDES permit. This equates reclaimed water usage to an optional conjunctive use to normal wastewater discharge. A non-conjunctive reclaimed water system would require the disposal of wastewater through the reclaimed system. For example, if a NPDES permit discharge amount is exceeded, the reclaimed system could utilize the exceeded amount to ensure that all discharged wastewater was legally discharged and permitted.

North Carolina reclaimed water regulations for effluent quality are also split into type I and type II categories depending on the type of use for the reclaimed water. Type I reclaimed water treatment processes are defined as a treatment for uses such as: irrigation, cooling, and other uses where there is a low probability of the reclaimed water being ingested by humans. Type II reclaimed water treatment is defined as treatment for uses such as the irrigation of food chain crops (Risgaard, 2014, pers. comm.).

The system recommended by McGill Associates in the Reclaimed Water Study for the GAP and WWTP is a conjunctive system, and the proposed uses described in the study fall under Type I treatment (Wightman, 2010). For these reasons, this report focuses on regulations regarding conjunctive systems and Type I reclaimed water quality.

WWTP EFFLUENT QUALITY & RECLAIMED WATER STANDARDS

North Carolina regulations for reclaimed water were revised in 2011, after the Reclaimed Water System Study was completed (North Carolina Administrative Code, 2011). Analysis of the water quality parameters, Table 3, for 2012 through 2014 show that 68% of the total 1096 days were sampled. These results indicate that the water quality of the Oxford WWTP effluent meets or exceeds the North Carolina Reclaimed Water Standards for tertiary quality treatment Type I uses in the majority of days sampled, the results are shown in Table 4.

Table 3: Type I – New Reclaimed Water Quality Requirements as of 2011 (NC Administrative Code, 2011)

Parameter	Form	Level
Biological Oxygen Demand (BOD_5)	Monthly Average Max	10 mg/L
	Daily Max	15 mg/L
Total Suspended Solids (TSS)	Monthly Average Max	5 mg/L
	Daily Max	10 mg/L
Ammonia (NH_3)	Monthly Average Max	4 mg/L
	Daily Max	6 mg/L
E. coli or *fecal coliform*	Monthly Average Max	14/100 mL
	Daily Max	25/100 mL
Turbidity	Maximum	10 NTUs

Out of the North Carolina reclaimed water quality parameters, TSS and fecal coliform had the highest number of daily maximum concentrations exceeding Type I water reclamation standards, 98% and 90% respectively, Table 4. Figure 4 shows a total of 16 cases where the effluent TSS concentration exceeded the Daily Maximum standard of 6 mg/L. Out of these 16 instances, measured concentration of TSS occurred mainly in January, February, and March, Table 5.

Figure 5 shows a total of 75 days where the daily fecal coliform geometric mean concentrations exceeded the daily maximum 25/100 mL reclaimed water standard. Out of the 75 instances, there was no temporal trend or specific months of concern.

Table 4: City of Oxford wastewater treatment plant's percentage of days sampled that meet or are below the daily maximum reclaimed water type I standards in the years 2012-2014.

Parameter	Percent Daily Max Meeting or Below Standard
Biological Oxygen Demand (BOD_5)	100%
Total Suspended Solids (TSS)	98%
Ammonia (NH_3)	99%
Fecal Coliform	90%
Turbidity	**--***

* Turbidity data is not currently collected.

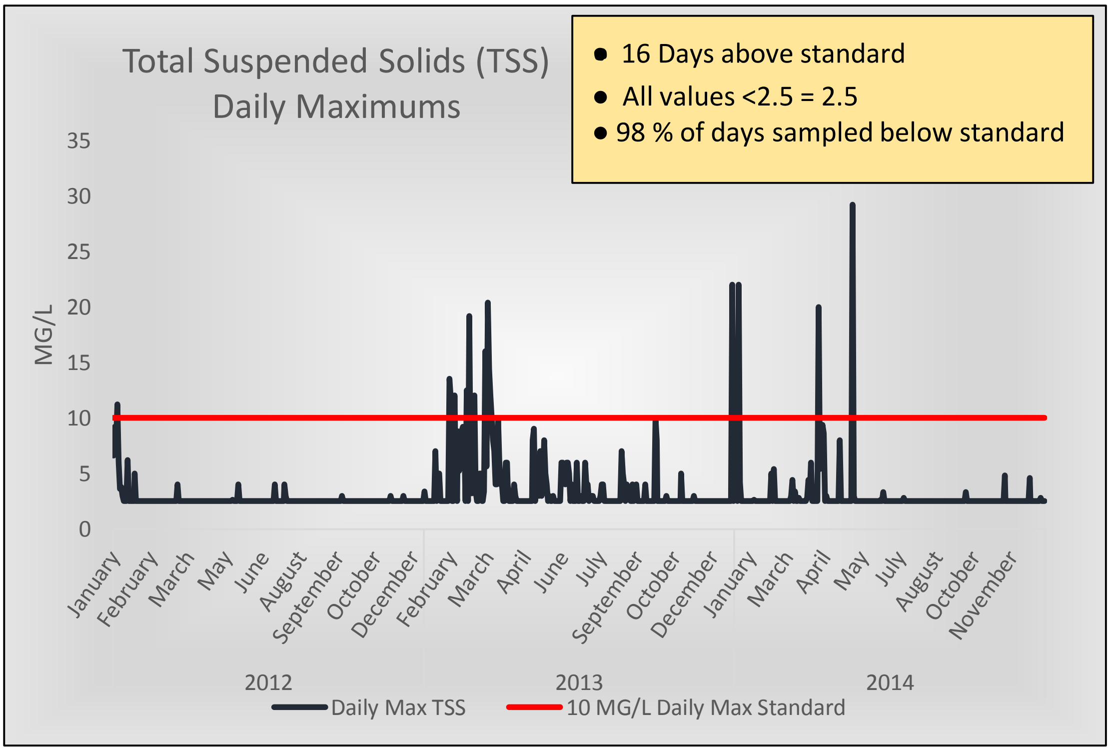


Figure 4: City of Oxford wastewater treatment plant's effluent total suspended solids (TSS) concentration from 2012-2014. The reclaimed water type I standard for TSS is 10 mg/L daily and is provided for reference.

Table 5: Total suspended solid days above the reclaimed water type I standard by month. The percentage of total values are the percentage of days above the standard out of the 16 total days above the standard.

Month	# Days Above Standard	Percent of Total
January	4	25%
February	5	31%
March	4	25%
April	1	6%
May	1	6%
June	0	0%
July	0	0%
August	0	0%
September	0	0%
October	0	0%
November	0	0%
December	1	6%
TOTAL	16	

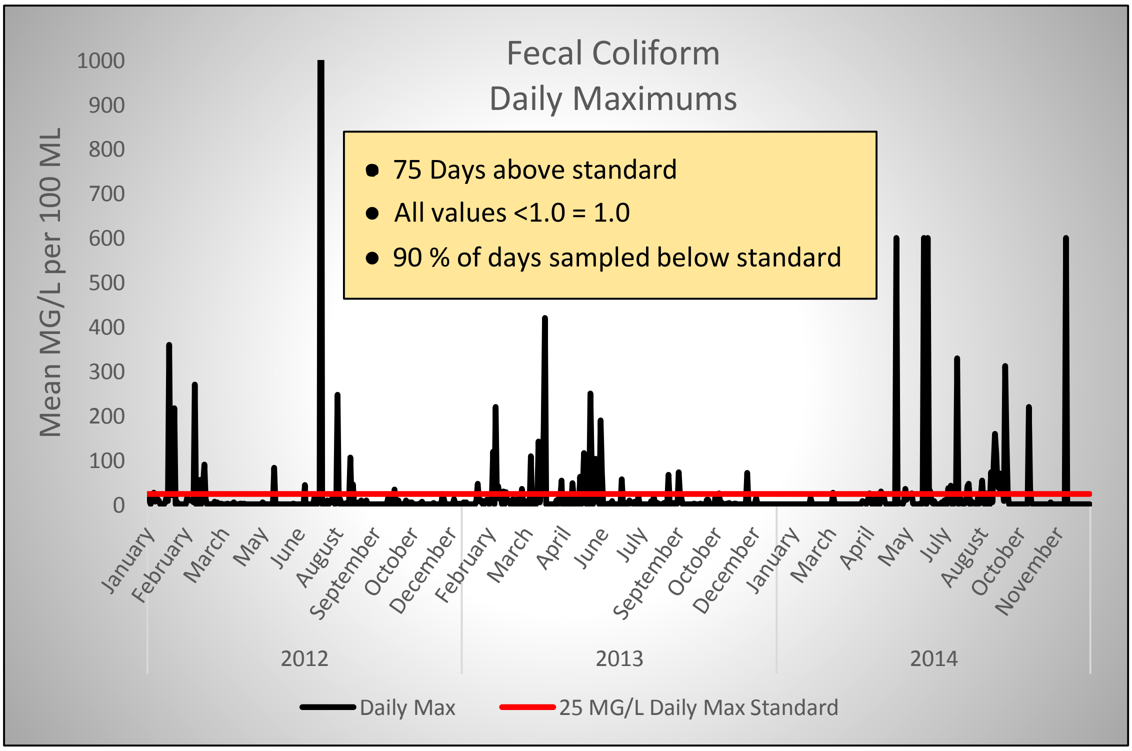


Figure 5: City of Oxford wastewater treatment plant's effluent fecal coliform daily maximum concentrations from 2012-2014. The reclaimed water type I standard for fecal coliform daily maximum is 25 mg/L and is provided for reference.

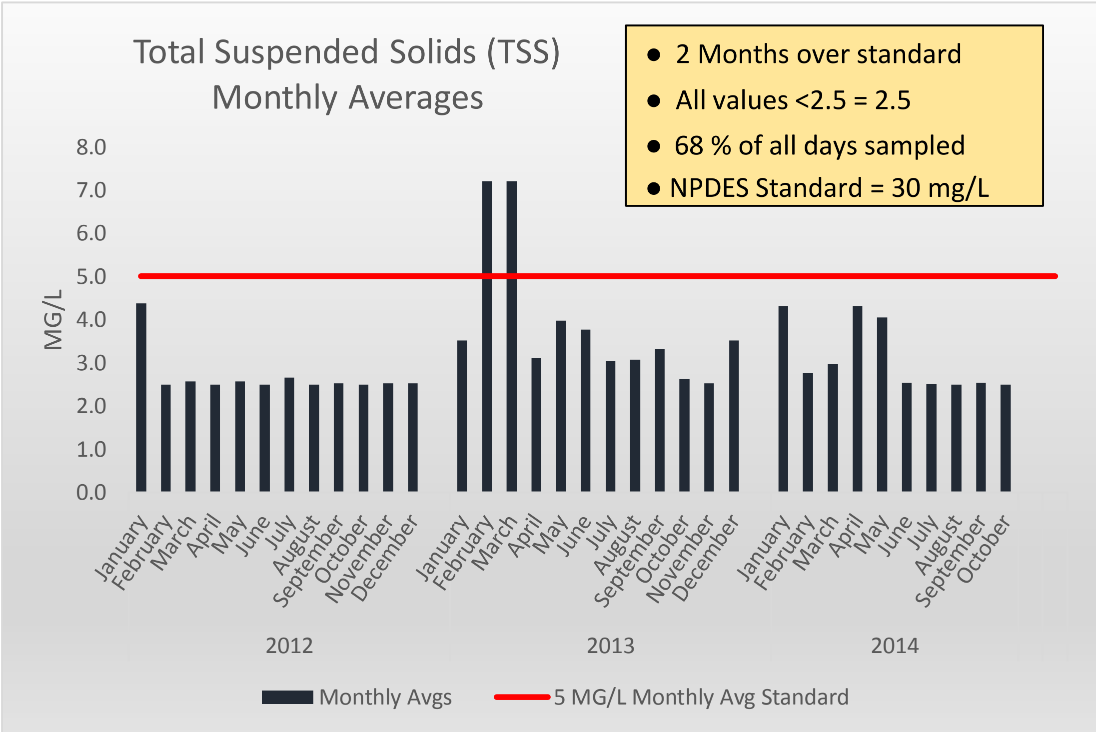


Figure 6: City of Oxford wastewater treatment plant's effluent total suspended solids (TSS) monthly average concentration from 2012-2014. The reclaimed water type I standard for monthly average TSS is 5 mg/L daily and is provided for reference.

The only water quality parameter to exceed the reclaimed water monthly average standard was total suspended solids (TSS). This occurred in two months (February and March) in the year 2013, Figure 6. All other parameters were below the monthly average maximum standards, Appendix Figure 21-23.

Based on the parameters measured, the quality of the Oxford WWTP effluent is high and the plant presents an excellent opportunity for water reclamation which agrees with the Reclaimed Water System Study assessment done in 2009 (Wightman, 2010). The two water quality parameters with the highest number of standard exceedances, TSS daily maximum and *E. coli/fecal coliform* daily maximum were below the state standard 98% and 90% of the days sampled respectively. The WWTP does not collect water quality data on turbidity. However the Reclaimed Water System Study competed by McGill Associates (Wightman, 2010) notes that with the tertiary sand filter in place at the WWTP it is assumed the effluent will meet the turbidity maximum standard of 10 Nephelometric Turbidity Units (NTU's). Of note is that all water quality data, when less than laboratory equipment sensitivity, was assumed to be equal to the equipment sensitivity threshold which conservatively elevates much of the water quality data reported. Even with this conservative assumption, the Oxford WWTP has a high quality effluent in the majority of days sampled and is suitable for water reclamation.

METHODOLOGY

Scenarios

The engineer average scenario is based on the Reclaimed Water System Study's estimate of daily average demand from the WWTP and GAP of 62,000/day, Table 6. This scenario is likely an overestimate of reclaimed water demand at the WWTP and GAP because the study itself reports that reclaimed water demand on most days would be much less (Wightman, 2010). In addition, this figure may not take into account seasonality which can commonly lower reclaimed water demand to zero during winter months in North Carolina (Dalton, 2014; Jordan, 2014; Parrish, 2014; all pers. comm.). Due to the likely overestimation of reclaimed water demand in the Reclaimed Water System Study, a more conservative base or minimum reclaimed water demand scenario was established.

The base-minimum and other water demand scenarios for the Oxford reclaimed water system are shown in Table 6. The base-minimum calculation uses the lower end estimates of 25,000 gallons/day and 32,000 gallon/day for the WWTP and GAP respectively from the Reclaimed Water System Study (Wightman, 2010). The GAP demand was also assumed to exist for only six months of a year given the seasonal nature of irrigation demand in North Carolina. Overall, the base-minimum water demand scenario is the most conservative.

The medium, high, and maximum demand scenarios are the summation of the base-minimum scenario and various reclaimed water demand amounts from non WWTP and GAP sources. The maximum reclaimed water demand is based on the reclaimed water system's submersible pump maximum rate of 500 gallons per minute working for 12 hours per day on an annual basis (Wightman, 2014). This maximum possible demand is a high estimate of demand however it may be useful for Oxford decision makers. At this maximum rate, the submersible pump would likely need to be replaced before the end of its predicted lifespan of 25 years. The medium and high scenarios were determined by dividing the difference between the maximum and base-minimum scenarios into three (38.8 million gallons per year (MGY)) or 1/3 percentiles. The medium scenario is equal to the addition of the base-minimum scenario and 38.8 MGY. The high scenario is equal to the addition of the base-minimum scenario and 2 times 38.8 MGY.

Table 6: Reclaimed water demand scenarios. The base-minimum scenario assumed low demand estimate for the WWTP and GAP with GAP demand to be for only half the year given the seasonality of irrigation demand. The max scenario is based on maximum equipment pumping rate operating for 12 hours per day. The Engineer Avg scenario is based on the Reclaimed Water System Study daily average and is presented as a reference; most days would be much lower than this average. The medium and high scenarios are spaced at 1/3 intervals between the max and base-minimum. The

medium, high, and max scenarios all have the same amount of wastewater treatment plant (WWTP) and Granville Athletic Park (GAP) reclaimed water demand as the base case plus water demand from non WWTP and GAP sources. The Percent of average discharge is based on an average of 1.1 MGD discharge from the WWTP calculated for 2010-2013. Million gallons per year are rounded to the nearest whole number.

Scenarios	Base-Minimum	Engineer Avg	Medium	High	Max
Million Gallons per Year	15	22.5	54	93	131.5
% of Avg WWTP Discharge	3.5%	5.25%	12.5%	21.5%	30.5%
Environmental Impact Model % Range	0-10%		10-20%	20-30%	30-40%

Economic Analysis Methodology: Incremental Cash Flow Model

The incremental cash flow is a net cash flow or the difference two investments. An incremental cash flow therefore takes into account foregone and added benefits/costs of a project. The incremental cash flow in this study is an Excel based deterministic model. The incremental cash flow and subsequent analysis is presented to be a decision making aid for the City of Oxford to determine whether to follow through with a reclaimed water system and if so, how much water to reclaim.

Incremental Cash Flow Assumptions

Several assumptions were made in creating the incremental cash flow model, Appendix Table 34. Assumptions and time frame details are listed in Table 7. The net present value of this project is invariant to inflation when cash flows, regardless of perspective, are unaffected by accounting, taxes, or other rules which create temporal differences between actual and computed cash flows for specific project actors. In this study, I have setup the cash flow to the Oxford community so that, by definition, no timing or distributional differences are taken into account. Therefore, the net present value is insensitive to inflation (Conrad, 2015, pers. comm.). In addition, the value of the land which would be used for water reclamation equipment is assumed to have a present value equal to its future value, making its net present value zero.

Table 7: Incremental cash flow assumptions and time frame.

Incremental Cash Flow Assumptions		
Economic depreciation of reclaimed water system equipment, infrastructure	-0.316% = economic depreciation rate of public utilities	(Hulten & Wykoff, 1980)
Reclaimed water system lifespan	–25 years – based on submersible pump lifespan –equipment salvaged after 25 years	(Wightman, 2014, pers. comm.)
Oxford nominal discount rate	-4% - rate last charged to City for water infrastructure financing	(Belton, 2014, pers. comm.)
Reclaimed water labor/ non-labor cost percentage	40:60 %	(NRC, 2012)
Project time frame	–Construction 2015-2017 –Operation 2017 onwards	(Wightman, 2010)

The cash-in items for the incremental cash flow are foregone costs (costs savings) of purchasing, treating, and pumping potable drinking water due to reclaimed water usage; reclaimed water revenue (both fixed and variable); and loan proceeds if the project is financed. The cash-out items include: reclaimed water system investments (WWTP upgrades and route), reclaimed water cost on a per gallon basis, foregone drinking water revenue, and loan expense if the project is financed to some degree, Appendix Table 34.

I assumed that the City of Oxford owns and operates the reclaimed water system, which was recommended by the Reclaimed Water System Study (Wightman, 2010). The WWTP reclaimed usage was assumed to yield no revenues because the WWTP is owned by the City. The Granville Athletic Park (GAP) reclaimed usage does not have any associated drinking water cost savings because the GAP is currently irrigated by rain fed ponds and not by potable water. Utilizing reclaimed water at the GAP therefore will not displace any potable water costs for the City of Oxford. Reclaimed water used by the GAP was assumed to create revenues for the City of Oxford. All other reclaimed water use has associated revenues, costs, and foregone drinking water cost savings.

Incremental Cash Flow Parameters

The base-minimum input parameters or base case to the reclaimed water incremental cash flow are presented in Table 8. Prices and costs are in 2014 nominal dollars. These input parameters are shared between all reclaimed water demand scenarios except ‘quantity of reclaimed water other (gallons) which is varied for each scenario, Table 6. Initial inputs are projected over 25 years.

Table 8: Base-Minimum Incremental Cash Flow Input Parameters.

Parameters - Prices in 2014 Nominal Dollars	
Quantity of Reclaimed Water WWTP (gallons)	9,125,000
Quantity of Reclaimed Water GAP (gallons)	5,840,000
Quantity of Reclaimed Water Other (gallons)	0
Initial Usage Rate of Reclaimed Water per gallon	$0.00206
Percentage of Reclaimed Revenues from Fixed Fees	50%
Initial Avg Cost of Reclaimed Water per gallon	$0.00247
Initial Avg Cost of Drinking Water per gallon	$0.00208
Initial Avg Revenue of Drinking Water per gallon	$0.00377
Percent of Reclaimed Water Cost Labor	40.0%
Percent of Reclaimed Water Cost Other	60.0%
Growth of WWTP Reclaimed Water Demand	0.0%
Growth of GAP Reclaimed Water Demand	0.0%
Growth of Other Reclaimed Water Demand	0%
Growth of Real Reclaimed Water Price	0.957%
Growth of Real Avg Cost of Reclaimed Water Non-Labor Component	3.511%
Growth of Real Avg Revenue of Drinking Water	0.957%
Growth of Real Avg Cost of Drinking Water	3.511%
City of Oxford Nominal Interest Rate	4%
Long Term Inflation Growth	2%
Long Term Real Earnings (labor cost) Growth	1.4%
Investment Cost	2,055,148
Percent Financed	50%
City of Oxford Real Discount Rate*	2%

*The Oxford Real Discount Rate = (1+nominal discount rate)/(1+inflation growth)-1 (Boadway, 1979)

Drinking Water Revenues & Costs

The average revenue of drinking water per gallon was calculated by dividing Oxford water sales by total gallons used, Table 9. The average of FY 2011 to 2014 revenue (in 2014 nominal dollars) was the value utilized for the initial revenue per gallon of drinking water in the incremental cash flow, Table 9, Table 11.

Table 9: Oxford Revenue of Drinking Water per Gallon. The gallons used on a fiscal year basis were provided by the Kerr Lake Regional Water System (KLRWS). Water sale revenues are reported in the City of Oxford comprehensive annual financial reports. Nominal Revenue per gallon values were adjusted to 2014 dollars with inflation, measured as the World Bank GDP Implicit Deflator, and the price index for utility gross output measured by the US Bureau of Economic Analysis (World Bank, 2015; BEA, 2014).

Fiscal Year	Gallons Used (Million Gallons)	Water Sales (Dollars)	Nominal Revenue per Gallon (Dollars)	Nominal Revenue per Gallon (2014 Dollars)
2010-2011	435.608	1,509,043	0.00346	0.00370
2011-2012	438.927	1,660,651	0.00378	0.00390
2012-2013	469.629	1,626,530	0.00346	0.00367
2013-2014	457.994	1,755,673	0.00383	0.00383

The average cost of drinking water per gallon was calculated by dividing the total cost of purchasing, treatment, and pumping of drinking water by the total number of gallons consumed. Only the drinking water purchase, treatment, and pumping costs were considered as costs in this analysis because the cost of using a gallon of reclaimed water would displace only these specific drinking water costs. In other words, all other drinking water costs (infrastructure maintenance, billing costs) other than purchase, treatment, and pumping would be incurred by the City of Oxford regardless if a gallon of reclaimed water or drinking water was used. The average of FY 2011 to 2014 cost per gallon (in nominal 2014 dollars) was the value utilized for the initial cost per gallon of drinking water in the incremental cash flow, Table 10, Table 11.

Table 10: Oxford Cost of Drinking Water per Gallon. The gallons used on a fiscal year basis were provided by the Kerr Lake Regional Water System (KLWRS). Purchase, pumping, and treatment costs are reported in the City of Oxford comprehensive annual financial reports. Nominal cost per gallon values were adjusted to 2014 dollars with inflation, measured as the World Bank GDP Implicit Deflator and the price index for utility intermediate inputs measured by the US Bureau of Economic Analysis (World Bank, 2015; BEA, 2014).

Fiscal Year	Gallons Used (Million Gallons)	Purchase, Pumping, & Treatment Cost (Dollars)	Nominal Cost per Gallon (Dollars)	Nominal Cost per Gallon (2014 Dollars)
2010-2011	435.608	829,005	0.00190	0.00204
2011-2012	438.927	918,694	0.00209	0.00213
2012-2013	469.629	919,890	0.00196	0.00211
2013-2014	457.994	935,049	0.00204	0.00204

Table 11: Oxford Average Revenue and Cost of Drinking per Gallon. These average revenue and cost values are the average of fiscal years 2010-2011, 2011-2012, 2012-2013, and 2013-2014 reported in 2014 dollars.

Avg Nominal Revenue per Gallon (2014 Dollars)	Avg Nominal Cost per Gallon (2014 Dollars)
0.00377	0.00208

Reclaimed Water Operations & Maintenance Costs

The Town of Holly Springs, North Carolina, located approximately 58 miles to the southwest of the City of Oxford, has a reclaimed water system that utilizes tertiary treated effluent with a comparable capacity to the proposed reclaimed system for the City of Oxford. The Holly Springs reclaimed system capacity is 1.5 MGD. The proposed Oxford capacity is 0.36 MGD, based on a maximum pumping rate of 500 gallons per minute operating 12 hours per day, Table 6 (Parrish, 2014; Wightman, 2014, both pers. comm.). Accordingly, Holly Springs was chosen as a proximate comparison for reclaimed water costs for Oxford because of its location and reclaimed system capacity. In choosing Holly Springs, reclaimed water operations and maintenance costs were assumed to be affected by system size (NRC, 2012).

The average operations and maintenance (O&M) cost of reclaimed water per gallon for Holly Springs was estimated based on reclaimed water revenues and fees. This assumption was used to estimate reclaimed water O&M costs because many reclaimed water costs, electricity or billing for example, are jointly accounted for and thus indistinguishable between sewer and drinking water systems. Jointly accounting these costs is a common local government practice. Therefore directly accounting for O&M reclaimed water costs for Holly Springs was not possible. In estimating reclaimed water O&M costs, it was assumed that reclaimed revenues would be proportional to reclaimed costs. The following equation was used to estimate reclaimed O & M costs out of the larger Water and Sewer Fund which includes the sewer, reclaimed, and drinking water systems.

$$\frac{Reclaimed\ Water\ Revenues}{Water\ \&\ Sewer\ Fund\ Revenues} * Water\ \&\ Sewer\ Fund\ Expenditures = Reclaimed\ O\&M\ Costs$$

Reclaimed water revenues equal the sum of usage revenue, inspection fee, reclaimed capacity fees, and reclaimed fees in lieu. Debt service expenditure and interest based income were not included in the above calculation. The reclaimed cost values were calculated for fiscal years 2010-2011, 2011-2012, 2012-2013, and 2013-2014 and divided by total gallons used for respective years to arrive at average cost per gallon, Table 12 and Appendix Table 35 - Table 38.

Table 12: Holly Springs average operations and maintenance cost of reclaimed water per gallon. Reclaimed usage data was provided by the Town of Holly Springs Reclaimed Water Coordinator Jeff Peters. Nominal cost per gallon values were adjusted to 2014 dollars with inflation, measured as the World Bank GDP Implicit Deflator, the average percentage change of the 2010-2014 price index for utility intermediate inputs measured by the US Bureau of Economic Analysis, and the Civilian Workers Employment Cost Index for Total Compensation from the US Bureau of Labor (Bureau, 2015; World Bank, 2013; BEA, 2014). In adjusting costs of labor it was assumed that reclaimed water costs were 40% Labor and 60% non-labor (NRC, 2012).

Fiscal Year	Gallons	Nominal Cost per Gallon (2014 Dollars)
2010-2011	61,799,000	0.00226
2011-2012	55,040,700	0.00244
2012-2013	68,953,300	0.00290
2013-2014	74,149,410	0.00256
Average		**0.00254**

The average estimated reclaimed water O&M costs for Holly Springs, NC, are slightly more than double the highest National Research Council (2012) national survey reported costs when 2014 dollars are compared, Appendix Table 39. The differences in costs are possibly due to facility scale. The Holly Springs system capacity is 1.5 MGD compared to the capacity of the systems in the NRC survey which range from 5-40 MGD.

Reclaimed Water Rate/Revenue

The National Research Council 2012 study on reclaimed water surveyed reclaimed water systems to determine the national landscape of reclaimed water rates. The survey found that reclaimed water rates were found to be on average 39% of drinking water rates and reclaimed water rates ranged from 11-75% of drinking water rates. Similarly, in a 2007 national survey, the American Water Works Association (AWWA) found reclaimed water rates to be on average from 50-100% of drinking water rates with a median of 80% (AWWA, 2008).

Several North Carolina reclaimed water systems in the Research Triangle area, which is near Oxford, were also surveyed in this study for their reclaimed water rates. The town of Holly Springs charges 50% of their highest tier drinking water rate for reclaimed water which is $3.75 per 1000 gallons (Parrish, 2014, pers. comm.). The town of Cary, NC, sets its reclaimed rate at its lowest drinking water tier rate of $3.60 per 1000 gallons (Jordan, 2014, pers. comm.). In Raleigh, NC, the reclaimed water rate is set as half the potable irrigation tier rate when there are no associated wastewater charges and slightly less for no associated wastewater charges: $2.54 and $1.48 inside city limits and $5.07 and $2.95 outside city limits (Dalton, 2014, pers. comm. communication). The City of Durham, NC, offers reclaimed water from its WWTP at no cost to users, however Durham does not own or maintain a distribution system (Dodson, 2014, pers. comm. communication). Durham reclaimed water transport is the responsibility of the end-user and is done by truck. Chapel Hill, NC, charges $2.18 to non-university customers per 1000 gallons of reclaimed water and $0.60 per 1000 gallons to university customers (Davis, 2014, pers. comm. communication).

Given the above landscape of reclaimed water rates on local and national scales, the reclaimed water usage rate for this study was set at $2.06 per 1000 gallons which is 50% of the uniform rate the City of Oxford charges for potable water within city limits (no tiers, uniform rate of $4.11 per 1000 gallons). This rate was used as the base rate in all reclaimed water demand scenarios. A rate set at half the potable rate is within the range of both the NRC and AWWA reclaimed water rate national surveys and equal to what local governments charge for reclaimed water i.e., Holly Springs and Raleigh. Further sensitivity analysis captures a reclaimed usage rate of between 40% and 80% of the potable rate within city limits.

In addition to a usage or volumetric rate for reclaimed water, some reclaimed systems have associated fixed fees. These are present in the form of fees for development, hookup, meter, and other monthly or annual fees that are charged independent of quantity used. The California Urban Water Conservation Council recommended a 70/30 percentage breakdown for percentage of volumetric revenue to fixed revenue as a water conservation best management practice (CA Urban, 2014). Larger water utilities generally have a breakdown of between 70-85/15-30 percent volumetric and fixed revenues while smaller utilities have a breakdown of between 50-70/30-50 percent (Eskaf, 2015, pers. comm.).

The City of Oxford is reasonably assumed to be a small utility. The actual volumetric to fixed revenue breakdown for the City of Oxford would again depend on political willingness to pay, makeup of water users, and city budgetary as well as conservation goals. For this study, the base case scenario has a 50/50 percentage breakdown of volumetric to fixed revenue where fixed fees are dependent on usage fees. The fixed percentage will be varied between 30 and 70 percent of total reclaimed revenue in further sensitivity analyses based on common small utility volumetric to fixed revenue percentages (Eskaf, 2015, pers. comm.).

Average Annual Growth Projections

The long term average annual projections for inflation and growth of real earnings (labor cost or labor compensation) are shown in Table 13. Data were obtained from the Congressional Budget Office (CBO) 2014 Long Term Budget Outlook (2014). These average annual values were applied cumulatively to prices in subsequent years for inflation, starting in 2015. Cost of Labor was adjusted to 2015 using the growth of real earnings from the 2014 all civilian workers December to December US Bureau of Labor Statistics Employment Cost Index for total compensation (Bureau, 2015). Adjusting the cost of labor beyond 2015 was done cumulatively with the CBO 2014 Long Term Budget Outlook growth in real earnings.

Table 13: Long Term Projection Values for Inflation and Real Earnings (Cost of Labor). The following two growth factors were used in long term cash flow projections. The growth in the US GDP Implicit Deflator and growth of real earnings from the Congressional Budget Office Long Term Budget Outlook (2014).

Average Annual Long Term Projections	
Inflation (GDP Deflator)	2.0 %
Real Growth in Earnings (Labor Compensation)	1.4 %

(CBO, 2014, pg 104)

The U.S. Bureau of Economic Analysis average percentage change for the years 2010-2013 from the utility sector chain-type price Indexes for Intermediate Inputs was used as the cumulative real growth in the average cost of reclaimed water non-labor component and the average cost of drinking water non-labor component starting in 2017 and subsequent years,

Table *14*. The average percent change for the years 2010-2013 from the utility sector chain-type price indexes for gross output was used as the cumulative real growth in real reclaimed water revenue per gallon and real drinking water revenue per gallon starting in 2017 and subsequent years, Table 15. The average percent change for either index was calculated for the last 4 years (2010-2013) due to the fact that 2009 is somewhat of an outlier of high negative growth due to the economic downturn/recession, especially for the intermediate inputs index (Appendix Figure 26 and Figure 27).

Table 14: The average % change of this index was used for the cumulative real growth in the average cost of reclaimed water non-labor component and the average cost of drinking water non-labor component, from the U.S. Bureau of Economic Analysis (2014).

Utility Sector Chain-Type Price Indexes for Intermediate Inputs (2009=100)					
Year	2009	2010	2011	2012	2013
Index Value	100.00	111.75	115.53	107.38	113.79
% Change	-27.25%	11.75%	3.38%	-7.05%	5.96%
Long Term Projection Value: Average % Change (2010-2013)					-27.25%

Table 15: The average % change of this index was used for cumulative real growth in real reclaimed water revenue per gallon and real drinking water revenue per gallon in the incremental cash flow, from the U.S. Bureau of Economic Analysis (2014).

Utility Sector Chain-Type Price Indexes for Intermediate Inputs (2009=100)					
Year	2009	2010	2011	2012	2013
Index Value	100.00	102.33	103.99	99.45	103.67
% Change	-6.51%	2.33%	1.62%	-4.37%	4.24%
Long Term Projection Value: Average % Change (2010-2013)					0.96%

Reclaimed Water Investment Costs: WWTP Upgrades & Consideration of a Reclaimed Water Pipe Route from the WWTP to GAP

In choosing a reclaimed water route, the City of Oxford should consider the potential for reclaimed water users/use and the cost of infrastructure. Figure 28-Figure 32 in the appendix illustrate the proposed routes of the McGill Associates Reclaimed Water System Preliminary Engineering Report. Based on preliminary analysis, Route D, Figure 31, has the most potential for reclaimed users in addition to the WWTP and GAP. In particular, a Walmart store, Oxford Housing Authority building, Speed Eez car wash, and Macra Lace Co. Factory Outlet are within 1000 feet of Route D. The Macra Lace Co. Factory was the 3rd largest industrial water user in Oxford in 2007-2008, Table 16 (West, 2010). In addition, Ideal Fastener Corporation, Bridgestone Bandag Tire, and CertainTeed Corporation are located within close distance however beyond 1000 feet, to Route D, Appendix Figure 31; these organizations represent the 5th, 4th, and 2nd largest industrial/commercial water users in Oxford for 2007-2008 respectively, Table 16. If extensions are built for Route D, the reclaimed water system could service the 2nd

through 5th largest industrial/commercial water users, as reported in 2007-2008, in the City, assuming these users have significant non-potable water demand.

Table 16: 2007-2008 top 12 Industrial/commercial water users in the City of Oxford, NC according to the Water and Wastewater 30-year Master Plan (West, 2010). Revlon Inc. used about 10% of Oxford's daily average demand in 2007-2008.

2007-2008 Top 12 Industrial Water Users in Oxford		
1	Revlon Inc.	1501 Williamsboro St
2	CertainTeed Corp.	200 Certainteed Dr
3	Macra Lace Co.	204 W Industry Dr
4	Bridgestone Bandag Tire	505 W Industry Dr
5	Ideal Fastener	603 W Industry Dr
6	Universal Leaf	Industry Dr
7	Masonic Home	600 College St
8	Granville Medical Center	1010 College St
9	Town of Stovall	-
10	Oxford Housing Authority	Various
11	Gate Precast Co.	3800 Oxford Loop
12	Brantwood Nursing	1038 College St

For the purposes of the incremental cash flow analysis of the proposed reclaimed water project, the 2014 investment costs of the 5 routes were averaged to yield one route cost, Table 17. The route costs were averaged because it is unknown which route the City of Oxford will choose based on cost, reclaimed water use potential, and other factors. In addition, before choosing a route based on reclaimed water demand potential a more in-depth market study should be conducted which is beyond the scope of this project (AWWA, 2009). McGill and Associates previously attempted a preliminary market study of reclaimed users for the 2009 Reclaimed Water System Study, however they found Oxford organizations to be unwilling to discuss their water usage which could be fulfilled with non-potable reclaimed water (Wightman, 2014, pers. comm. communication). Further work is needed to research the market for reclaimed water in the City of Oxford.

Table 17: Oxford reclaimed water system investment costs. Nominal cost per gallon values were adjusted to 2014 dollars with inflation, measured as the World Bank GDP Implicit Deflator, the price index for utility intermediate inputs measured by the US Bureau of Economic Analysis, and the Civilian Workers Employment Cost Index for Total Compensation from the US Bureau of Labor (Bureau, 2015; World Bank, 2015; BEA, 2014).

Investment Costs (Nominal Dollars)		
	2009 Dollars	2014 Dollars
Route A	1,255,275	1,145,071
Route B	1,208,400	1,102,530
Route C	1,179,125	1,076,843
Route D	1,447,150	1,321,359
Route E	900,175	822,440
Route Avg	1,198,025	1,093,648
WWTP Upgrade	1,006,000	916,539

Environmental Impact Analysis Methodology: Bayesian Network Model

Description of Bayesian Networks

A Bayesian network model (BNM) is a graphical representation of the key factors of a system, and their conditional dependences (Varis, 1997; Korb & Nicholson, 2004; Jensen & Nielsen, 2007). BNMs are an increasingly popular method to determine uncertainty in complex domains, including ecosystems, environmental management and problem diagnose (Uusitalo, 2007; Kahn et al., 1997). Compared to other traditional models, Bayesian networks have several advantages. First, they allow an estimation of the uncertainties and risks as probabilities which are better than models that only account for expected values (Uusitalo, 2007). Second, Bayesian networks are suitable for small and incomplete datasets. Kontkanen et al. (1997) illustrates that when dealing with smaller samples sizes Bayesian networks can predict results with accuracy. Another important feature of Bayesian network is the application of difference sources of knowledge. Bayesian networks can combine expert knowledge with real data in a mathematically sound way, especially when variables don`t have existing data. Last but not least, once the model is compiled, it can provide responses to queries rapidly (Uusitalo, 2007). In contrast, traditional simulation models take longer to simulate the result.

The two main components of a Bayesian network are 'nodes', representing the important concepts (or factors), and 'arrows', representing the relationship between those factors (with directions) (Kashuba et al., 2012). Arrows are represented by conditional probabilities (i.e. the likelihood of any particular outcome depends on the occurrence of preceding events). A node from which the arrow points is defined as a 'parent node', and the node toward which an arrow points is called a 'child node'. The dependencies are depicted as arrows connecting a 'parent node' to a 'child node' resulting in a directed acyclic graph (DAG) (Uusitalo, 2007). In other words, this network is defined in terms of two components: qualitative components and quantitative components. For the qualitative component, BNMs are a DAG where each node represents one of the variables in the model, and the arrow linking two variables shows the existence of statistical dependence between them (Aguilera et al. 2011). For the quantitative component, there is a conditional distribution p $(x_i|pa(x_i))$ for each variable X_i, where $pa(x_i)$ is its parents node (Kashuba et al., 2012).

Figure 7 depicts an example of DAG showing a simple Bayesian network with five nodes and five arrows. It indicates that both the physical and chemical states are conditional upon reclaimed water plan level (i.e., amount discharged to Fishing Creek). Child nodes relative to one concept can then be the parent nodes of another concept(s)(e.g. the physical conditions comprise the child node to reclaimed water plan and parent node to the biological conditions).

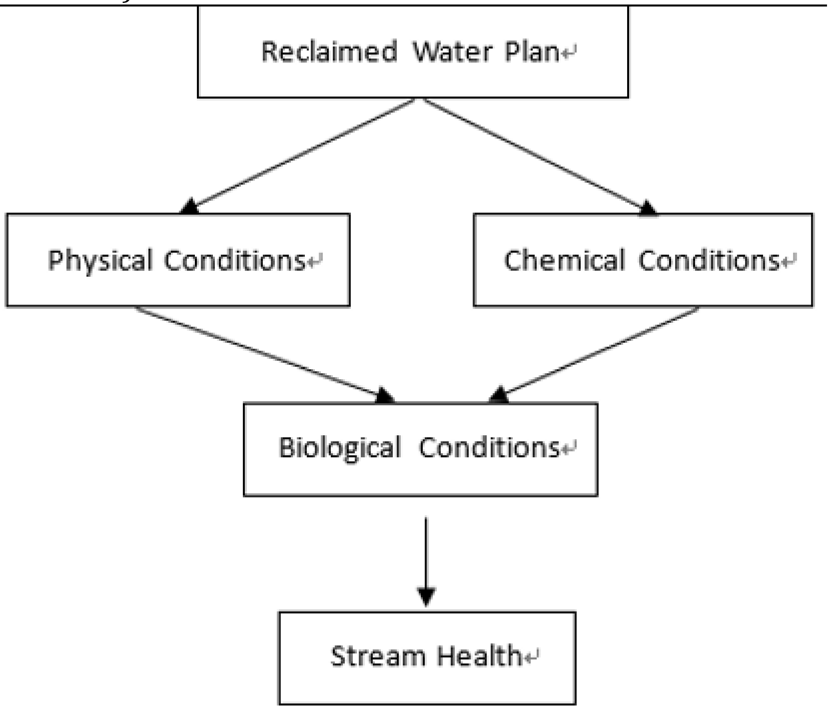


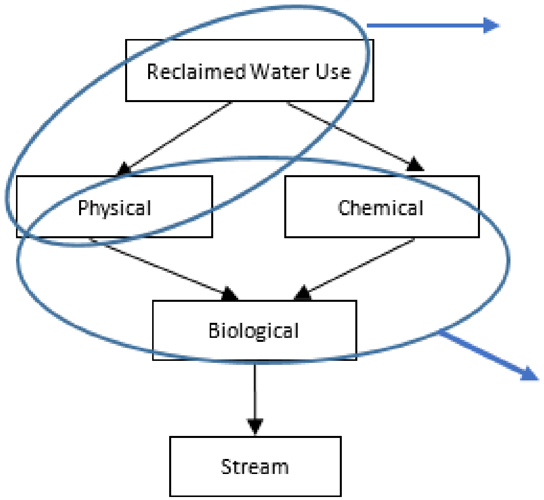
Figure 7: A conceptual Bayesian network answering the questions: a. what are the variables? and b. what are the relationship among these variables?

The mechanisms of Bayesian networks and its ability to quantify conceptual models with data is derived from the principles of Bayes Theorem (Bayes, 1763; Korb & Nicholson, 2004):

$$P(y|x) = \frac{P(y) \times P(x|y)}{P(x)}$$

Where:
P(y) is the prior probability of the child node
P(x) is the normalizing constant
P(x|y) is the probability distribution of x, given the data y
The network is quantified by populating a conditional probability table (CPT) associated with the nodes in the network. CPTs can be specified by experts` experience or from data, and depending on the complexity of the model any of several learning algorithms may be used (Jensen & Nielen, 2007). Conditional independence is fundamental to a Bayesian network (Korb & Nicholson, 2004). This property allows an examination of both the independent and interactive (conditional) effects of some specific environmental change on the modelled response variable (Aguilera et al., 2011). In addition, a Bayesian network requires the assumption of the Markov property (Korb & Nicholson, 2004), meaning that each CPT can be populated only after considering the immediate parent nodes of the node being quantified. For every possible combination of parent node values, a CPT indicates a probability distribution for values that are likely to occur at each of the various child nodes.

In the following simple example, Figure 8, a CPT is illustrated. The distribution of the CPT can be based on expert consultation or real data. Reclaimed water use can be classified as either low or high, and is the parent of the physical conditions node. If reclaimed water is used, this water does not enter the stream. The CPT for physical condition has two rows: low and high reclaimed water use. Each row provides the probability of observing either good or poor physical conditions given a known amount of reclaimed water not entering into the receiving stream. The probabilities in each row must add up to 100 percent, because each row describes a complete distribution across all possible child node values. The first row of the upper CPT, relating the reclaimed water and physical condition, indicates that if the reclaimed water use is low, then there is a 25 percent chance that resultant physical condition will be good, and a 75 percent chance that physical condition will be "poor". In other words, if 100 stream samples are selected from Fishing Creek watershed having low use of reclaimed water, 25 samples are likely to have good physical characteristics, but 75 samples might have poor characteristics.



Physical condition as CHILD node:

If reclaimed water use is…	Physical conditions will be…	
	Good	Poor
Low	25% of the time	75% of the time
High	85% of the time	15% of the time

Physical conditions as PARENT node:

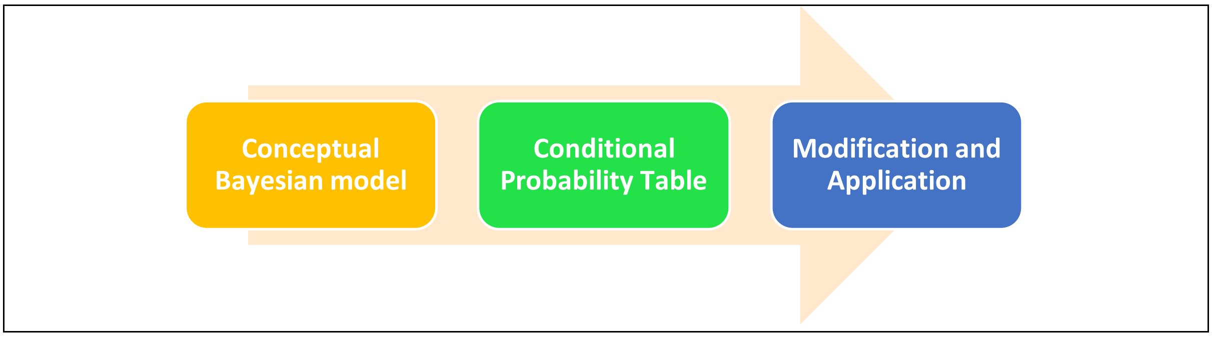
If physical condition is…	And chemical condition is…	Biological conditions will be…	
		Good	Poor
Good	Good	95%	5%
Good	Poor	60%	40%
Poor	Good	30%	70%
Poor	Poor	3%	97%

Figure 8: Example of simple conditional probability tables (CPT). The relation between each child node and its parents is specified with a CPT. The upper CPT illustrates the relation when reclaimed water use is the parent node, and physical conditions is/are the child node. The lower CPT illustrates the relation when physical conditions is the parent node (along with the chemical condition parent node), while biological condition(s) is/are the child node.

Creation of the Bayesian Networks

There are three main steps to create a Bayesian network model, shown in Table 18: a. create a conceptual Bayesian networks to answer the questions 'what are the variables' and 'what are the relationships between these variables' in a general way; b. create Conditional Probability Table (CPT) to quantify the conditional distribution of each variable; and c. modify model and apply the model. In order to better illustrate the conceptual Bayesian model, a Drive-Pressure-State-Impact-Response (DPSIR) is introduced to combine social activities with environmental ecosystem.

Table 18: Three main steps to create a Bayesian network model.



'DPSIR' Framework

There are several frameworks that have been developed and organized to describe the relationship between human activities and the environment. One such framework is the DPSIR framework which has been widely used to describe how human activities exert pressure on the environment and changing the quality and quantity of natural resources (EPA DPSIR).

In this DPSIR model, the water reclamation activities, defined as the driver, are input as 4 different scenarios. The Fishing Creek natural flow has been categorized into wet season, normal season, and dry season. The environmental states consider all the related environmental variables, both water quality and quantity, including dissolved oxygen, pH, and total suspended solids (TSS) etc. These variables will impact the stream ecosystem: fish community and macroinvertebrates. Based on the environmental impacts, this report will evaluate the reclamation scenarios and choose the optimal projection to provide practical guidance to the City of Oxford, Figure 9.

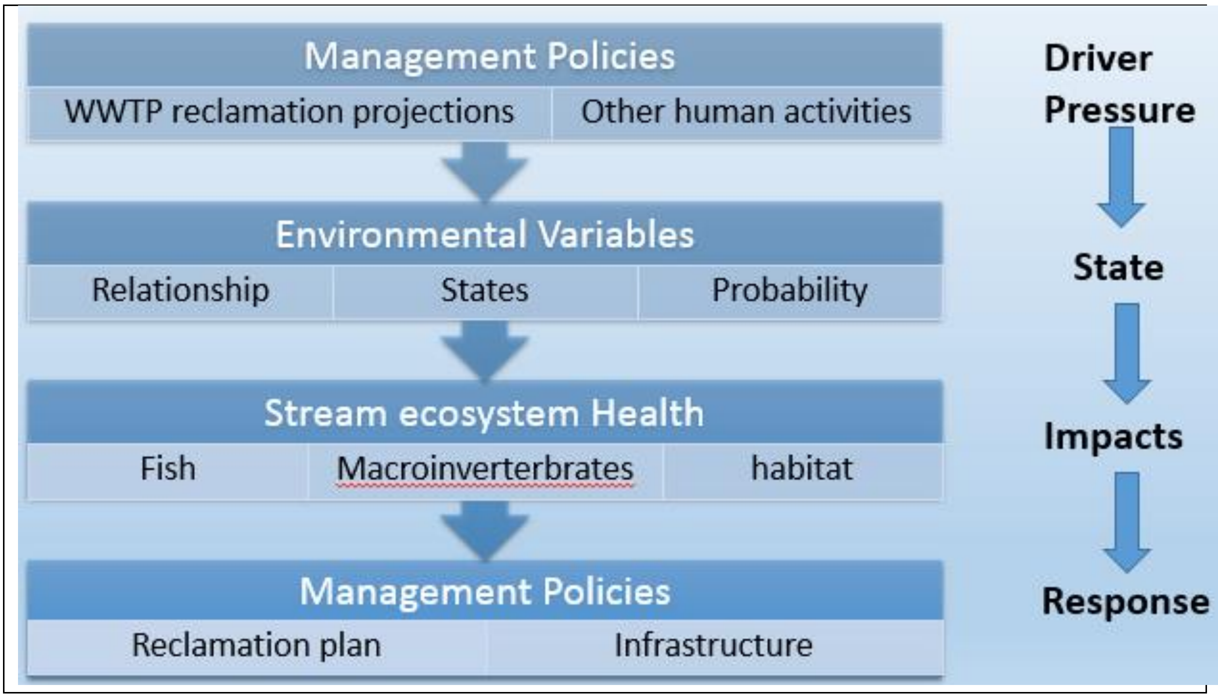


Figure 9: Drive-Pressure-State-Impact-Response (DPSIR) framework.

Bayesian Networks Using Expert Consultation

In order to develop this Bayesian network model (BNM), an expert team was created, including stream ecologists, water resource managers, biogeochemists, and hydrologists, listed in Table 19. Expert consultation refers to the interpretation of expert knowledge, including variable selection, and conditional probabilities for each variable (Reckhow et al., 2005; O'Hagan et al., 2006). Unlike data collected from a single study, experts provide an integrated estimation of system relations and uncertainties based on their academic experience and knowledge (Kashuba et al. 2012).

Table 19: Experts in stream ecology, water management, and biogeochemistry for the conceptual model

Name	Expertise	Others
Thomas F. Cuffney	Stream ecology & invertebrates	U.S. Geological Survey, North Carolina Water Science Center
Kristofor Voss	Stream ecology & Invertebrates	Ph.D. Candidate, Bernhardt Lab, Department of Biology, Duke University
Ben Colman	Stream ecology	Research Scientist, Bernhardt Lab, Department of Biology, Duke University
Kenneth Reckhow	Hydrologist	Professor Emeritus of Water Resources, Nicholas School of the Environment, Duke University
Bryn Tracy	Biological assessment & Water quality impact	NCDWR
James Heffernan	Aquatic ecology & biogeochemistry	Assistant Professor, Nicholas School of the Environment, Duke University
Peter Cada	Watershed management & water quality modeling	Tetra Tech, Consultant, Research Triangle Park, NC
Michael Paul	Stream ecology	Tetra Tech, Consultant, Research Triangle Park, NC

Variable Selection and Their States

This comprehensive model will depict the environmental impacts based on experts experience and knowledge. Figure 9 provides the structure of this model. To interpret such a structure into a conceptual BNM, relevant variables were selected. Three interviews and the review of relevant literature helped create the conceptual model. The conceptual model provides all possible variables that might have influence on the stream ecosystem and factors that might be seriously affected.

Based on the conceptual model, the current water quality and quantity data were compared with regulations and water quality standards for aquatic freshwater life from EPA and the North Carolina Department of Environment and Natural Resources (NC DENR). WWTP effluent zinc and dissolved oxygen concentrations were chosen as representative variables that are specifically important for the Fishing Creek ecosystem following expert advice, Table 19, and because they are the most likely to be non-compliant with aquatic freshwater life standards, Figure 2 and Figure 3. Compliance depends on both WWTP effluent concentrations and flow as well as Fishing Creek's natural discharge which is estimated through Reed's Creek, a nearby gauged stream.

Next the states of the selected variables were determined. There is a tradeoff between the model`s discriminatory strength and the accuracy of parameters (Kashuba R. et al. 2012). Uusitalo (2007) shows that if a variable is split into multiple states, it becomes more difficult to establish dependencies between variables. In addition, according to Kashuba (2010) it is often difficult for experts to distinguish between the middle two of four states; therefore, in most cases, the continuous variables are split into three states.

Conditional Probability Table (CPT)

CPTs concisely define the relations between the nodes represented by arrows. The probability distribution across the states of a given node changes depending on the state of nodes that influence it (i.e. parent nodes). Within each CPT, a probability distribution for all possible states of a child node must be elicited for all the combination of parent node states. Examples are shown in Figure 8. In this project, CPTs are created by expert consultation via a questionnaire made to collect all of the variable conditional probabilities. Each question consisted of a table, and the probabilities in each row must add up to equal 1.0; see example in Table 20.

Table 20: Example of a Conditional Probability Table for fish richness related to zinc concentration.

If zinc concentration is ...	Fish richness will be...	
	good	Poor
High	0.1	0.9
Low	0.7	0.3

The first row of the CPT indicates that if the Zinc concentration is high, then there is a 0.1 (10%) chance that fish richness will be good, and a 0.9 (90%) chance that the fish richness is poor. In other words, if 100 stream samples are taken having high Zinc concentration, then 10 samples are likely to have good fish richness, but 90 samples might have poor richness. The questionnaire used for the BNM of this is provided in the Appendix.

Data collection

Data used to create the Bayesian network were obtained from several sources:

1.) WWTP discharge water monitoring data from 01/01/2012 to 12/31/2014

2.) On site water quality sampling on Fishing Creek effluent site, upstream and downstream

3.) Water quality monitoring data on Fishing Creek site # SR1643 from North Carolina Department of Environment and Natural Resources (NC DENR, 2012; NC DENR, 1992-2012)

4.) Fish community, benthos, and habitat assessment data on Fishing Creek from NC DENR (NC DENR 1992-2012)

5.) Reed's Creek's discharge data from USGS, ranging from 1983/1/1 to 2015/3/12 (USGS 2015).

There have been few academic research projects on Fishing Creek and no discharge gauges are located along it, USGS or otherwise. However, Reed's Creek in Granville County, located 17 miles from Fishing Creek, has sufficient discharge data ranging from 1985 to 2015. The watershed in which Reed's Creek is located is 43 square miles which is similar to that of Fishing Creek`s watershed, 46.95 square miles. Therefore, discharge data on Reed's Creek was used as a proximate estimation of Fishing Creek's discharge for the BNM.

6.) Conditional probability data

Conditional probability data was obtained from expert experience and opinions which included stream ecologists, fish experts, WWTP manager, and NC DENR scientists. These data were collected via questionnaires and modeled using the Bayesian system described above.

RESULTS & ANALYSIS

Incremental Cash Flow Model Results

Table 21: Initial reclaimed water usage rate that sets net present value to zero in the incremental cash flow model for four reclaimed water demand scenarios. The percent potable usage rate is the percentage of the reclaimed usage rate out of the current City of Oxford inside city limits usage rate for potable water of $4.11 per 1000 gallons in nominal 2014 dollars.

Reclaimed Water Usage Rate that sets NPV=0				
	Base-Min	Medium	High	Max
$ per 1000 Gallons	7.59	2.71	2.37	2.24
% of Potable Usage Rate	184.6	65.9	50.6	54.5

The following tables and figures make-up a sensitivity analysis of six input parameters. The six input parameter were chosen because of their influence on net present value within the incremental cash flow i.e., the six input parameters had the largest percent change in NPV given a percent change in a respective input parameter. Variables not included in this analysis had less influence on the net present value. The 'base' refers to values used in all reclaimed water demand scenarios (base-minimum, medium, high, and max) for a given input parameter.

Table 22: The 2015 net present values of the four reclaimed water demand scenarios when the reclaimed water usage rate base of 50 % of the potable rate ($0.00206 per gallon in 2014 nominal dollars) is varied between 40-80% of the potable rate. The base value is 50% of the City of Oxford inside city limits potable water usage rate of $4.11 per 1000 gallons in nominal 2014 dollars.

Reclaimed Water Usage Rate				
% of Potable Rate	Base-Minimum	Medium	High	Max
40	-1,916,583	-2,620,863	-3,325,143	-4,029,423
45	-1,850,307	-2,114,128	-2,377,948	-2,641,769
50	-1,784,031	-1,607,392	-1,430,754	-1,254,115
55	-1,717,755	-1,100,657	-483,559	133,539
60	-1,651,479	-593,922	463,636	1,521,193
65	-1,585,203	-87,186	1,410,831	2,908,848
70	-1,518,927	419,549	2,358,025	4,296,502
75	-1,452,651	926,285	3,305,220	5,684,156
80	-1,386,375	1,433,020	4,252,415	7,071,810

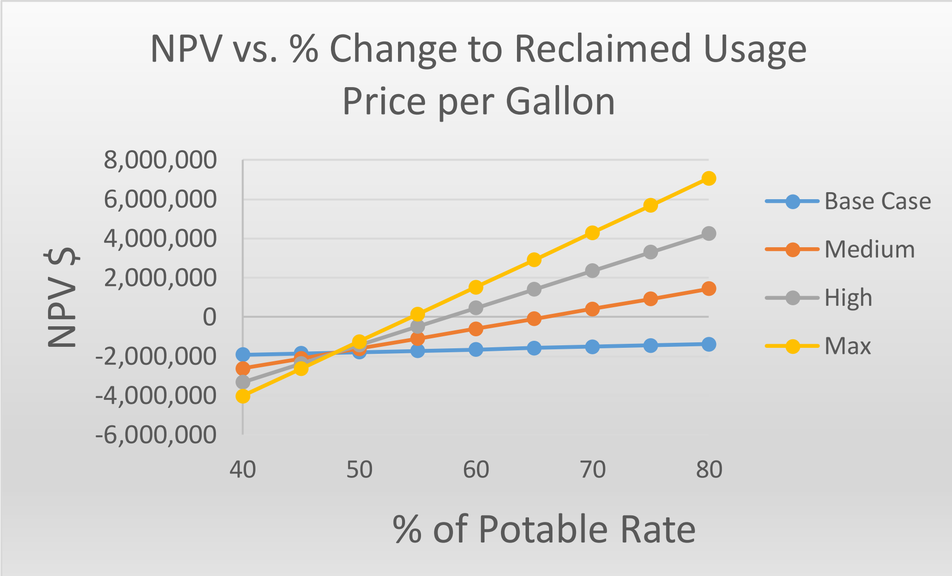


Figure 10: 2015 net present value vs. reclaimed water usage rate per gallon varied between 40-80% of the Oxford potable rate within city limits. The base value used in the four reclaimed water demand scenarios is 50% of the City of Oxford inside city limits potable water usage rate of $4.11 per 1000 gallons ($0.00206 per gallon (2014 nominal dollars).

Table 23: 2015 net present value vs. the percentage of reclaimed water total revenue is derived from fixed fees versus usage rate across four reclaimed water demand scenarios. The base case is 50% of reclaimed revenues are derived from fixed fees for the four reclaimed water demand scenarios.

Percentage of Reclaimed Revenues from Fixed Fees				
% Reclaimed Revenue Fixed	Base-Minimum	Medium	High	Max
30	-1,973,391	-3,055,208	-4,137,024	-5,218,841
35	-1,936,976	-2,776,782	-3,616,588	-4,456,394
40	-1,894,491	-2,451,951	-3,009,412	-3,566,872
45	-1,844,282	-2,068,061	-2,291,840	-2,515,619
50	-1,784,031	-1,607,392	-1,430,754	-1,254,115
55	-1,710,391	-1,044,353	-378,315	287,723
60	-1,618,341	-340,554	937,233	2,215,021
65	-1,499,991	564,331	2,628,653	4,692,974
70	-1,342,191	1,770,844	4,883,878	7,996,913

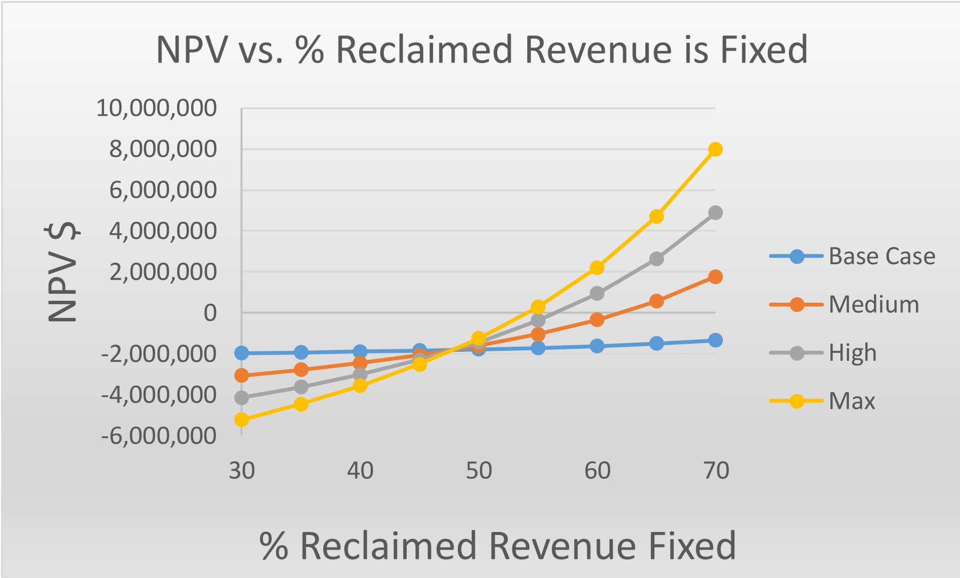


Figure 11: 2015 net present value vs. percentage of reclaimed water total revenue derived from fixed fees across four reclaimed water demand scenarios. The base percentage is 50% for all four reclaimed water demand scenarios.

Table 24: The 2015 net present values of the four reclaimed water demand scenarios when the average revenue of potable water per gallon is varied by +/- 20 % from the base value. The base average revenue of potable water is $0.00377 per gallon in 2014 nominal dollars for the four reclaimed water demand scenarios.

Initial Avg Revenue of Drinking Water per gallon				
% Change	Base-Minimum	Medium	High	Max
-20	-1,784,031	-798,800	186,432	1,171,663
-15	-1,784,031	-1,000,948	-217,865	565,219
-10	-1,784,031	-1,203,096	-622,161	-41,226
-5	-1,784,031	-1,405,244	-1,026,457	-647,670
0	-1,784,031	-1,607,392	-1,430,754	-1,254,115
5	-1,784,031	-1,809,541	-1,835,050	-1,860,559
10	-1,784,031	-2,011,689	-2,239,346	-2,467,004
15	-1,784,031	-2,213,837	-2,643,643	-3,073,448
20	-1,784,031	-2,415,985	-3,047,939	-3,679,893

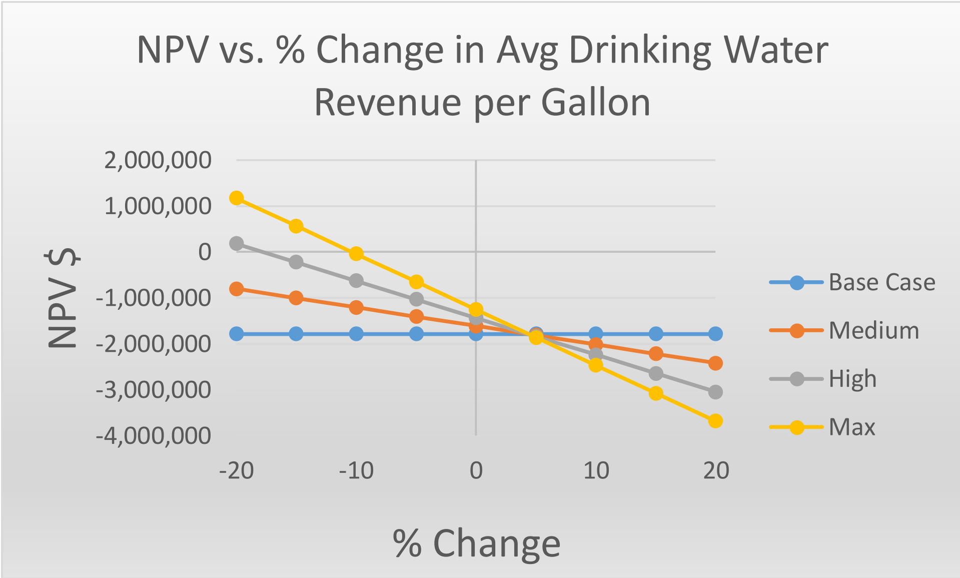


Figure 12: 2015 net present value vs. average potable water revenue per gallon varied +/- 20% from its base value of $0.00377 in 2014 nominal dollars across four reclaimed water demand scenarios.

Table 25: The 2015 net present values of the four reclaimed water demand scenarios when the average cost of reclaimed water per gallon is varied by +/- 20 % from the base value. The base initial average cost of reclaimed water is $0.00247 per gallon in 2014 nominal dollars.

Initial Avg Cost of Reclaimed Water per gallon				
% Change	Base-Minimum	Medium	High	Max
-20	-1,516,298	-645,292	225,713	1,096,718
-15	-1,583,231	-885,817	-188,404	509,010
-10	-1,650,164	-1,126,342	-602,520	-78,698
-5	-1,717,098	-1,366,867	-1,016,637	-666,407
0	-1,784,031	-1,607,392	-1,430,754	-1,254,115
5	-1,850,965	-1,847,917	-1,844,870	-1,841,823
10	-1,917,898	-2,088,442	-2,258,987	-2,429,531
15	-1,984,832	-2,328,968	-2,673,103	-3,017,239
20	-2,051,765	-2,569,493	-3,087,220	-3,604,948

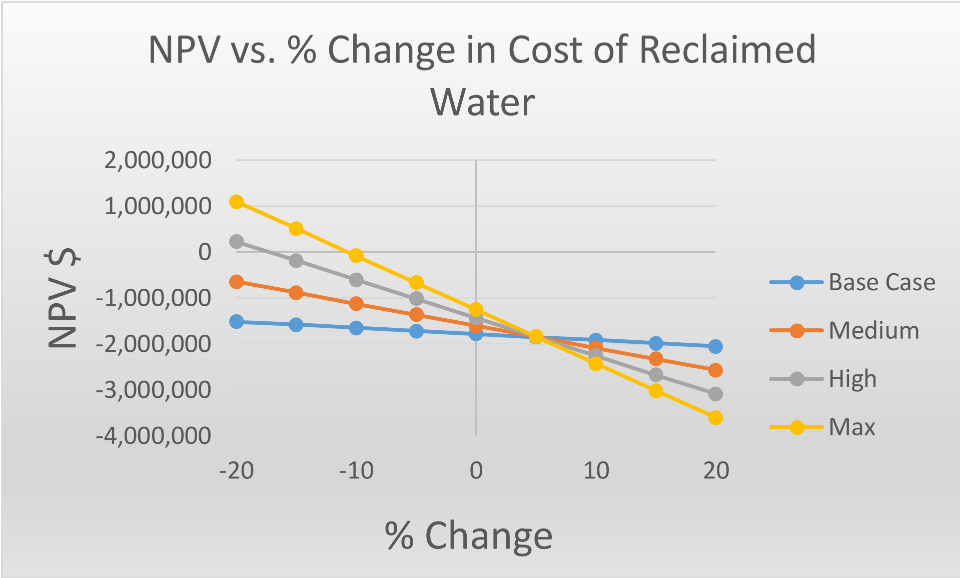


Figure 13: 2015 net present value vs. average cost of reclaimed water per gallon varied +/- 20% from its base value of $0.00247 in 2014 nominal dollars across four reclaimed water demand scenarios.

Table 26: The 2015 net present values of the four reclaimed water demand scenarios when the investment cost of the reclaimed water system is varied by +/- 20% from the base value. The base investment cost is $2,055,148 in 2014 nominal dollars for all four reclaimed water demand scenarios. The investment cost includes all route, engineering, construction, equipment, and wastewater treatment plant upgrade costs for the proposed reclaimed water system in the 2010 Reclaimed Water System Study (Wightman).

INVESTMENT COST				
% Change	Base-Minimum	Medium	High	Max
-20	-1,407,853	-1,231,214	-1,054,575	-877,937
-15	-1,501,898	-1,325,259	-1,148,620	-971,981
-10	-1,595,942	-1,419,303	-1,242,665	-1,066,026
-5	-1,689,987	-1,513,348	-1,336,709	-1,160,070
0	-1,784,031	-1,607,392	-1,430,754	-1,254,115
5	-1,878,076	-1,701,437	-1,524,798	-1,348,159
10	-1,972,120	-1,795,482	-1,618,843	-1,442,204
15	-2,066,165	-1,889,526	-1,712,887	-1,536,248
20	-2,160,209	-1,983,571	-1,806,932	-1,630,293

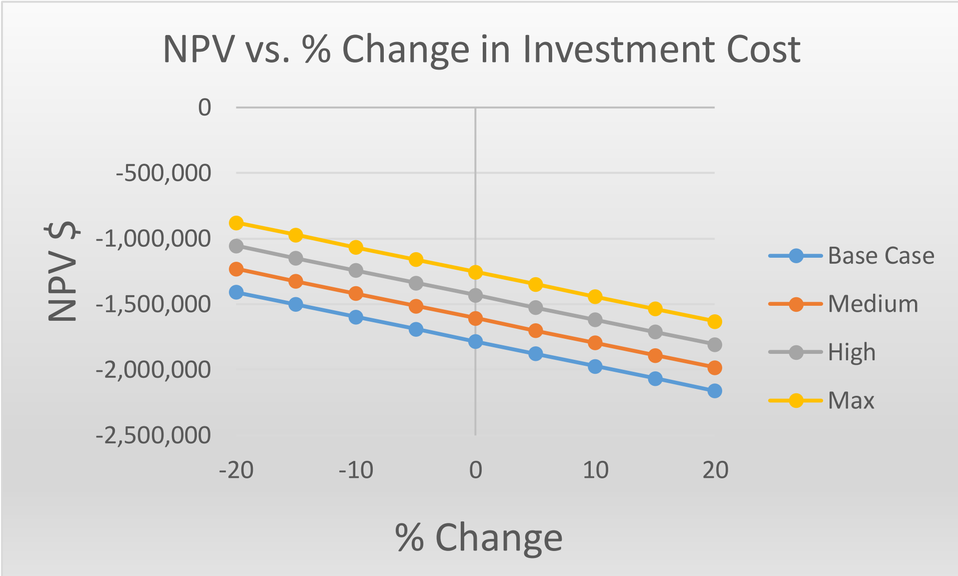


Figure 14: 2015 net present value vs. investment cost of the reclaimed water system varied +/- 20% from its base value of $2,055,148 in 2014 nominal dollars across four reclaimed water demand scenarios. The investment cost includes all route, engineering, construction, equipment, and wastewater treatment plant upgrade costs for the reclaimed water system.

Table 27: The 2015 net present values of the four reclaimed water demand scenarios when the real growth rate of the average reclaimed water non-labor cost is varied by +/- 20 % from the base value. The base growth rate is 3.511% which is the average % percent change of the years 2010-2013 of the Utility Sector Chain-Type Price Indexes for Intermediate Inputs (Bureau, 2014).

Growth of Real Avg Cost of Reclaimed Water Non-Labor Component				
% Change	Base-Minimum	Medium	High	Max
-20	-1,691,041	-1,273,232	-855,424	-437,615
-15	-1,713,238	-1,352,998	-992,758	-632,518
-10	-1,736,121	-1,435,226	-1,134,332	-833,438
-5	-1,759,711	-1,519,997	-1,280,283	-1,040,570
0	-1,784,031	-1,607,392	-1,430,754	-1,254,115
5	-1,809,106	-1,697,498	-1,585,889	-1,474,281
10	-1,834,959	-1,790,400	-1,745,842	-1,701,283
15	-1,861,616	-1,886,191	-1,910,767	-1,935,343
20	-1,889,102	-1,984,964	-2,080,826	-2,176,688

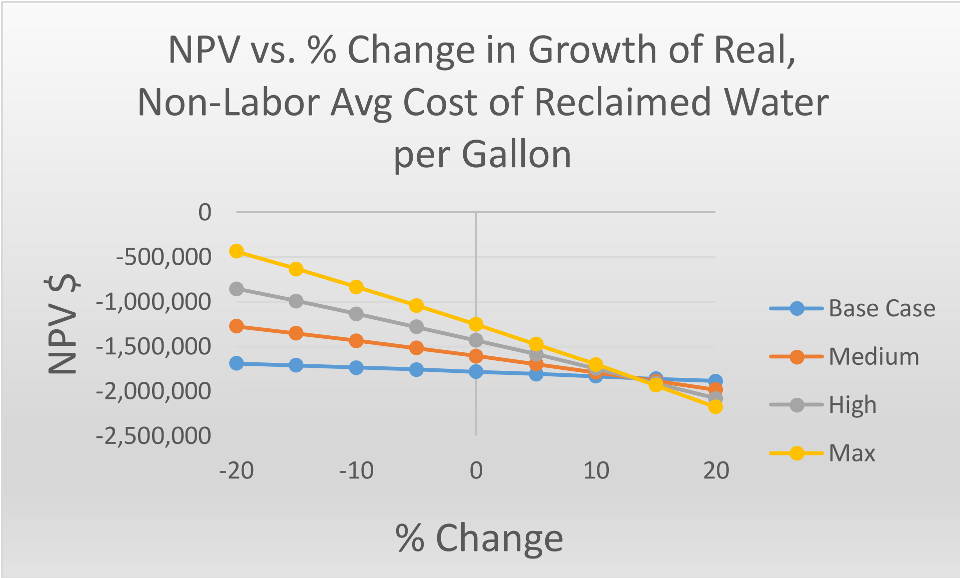


Figure 15: 2015 net present value vs. the real growth rate of average reclaimed water non-labor cost varied +/- 20% from its base value of 3.511% in all four of the reclaimed water demand scenarios. The base growth rate is the average % percent change of the years 2010-2013 of the Utility Sector Chain-Type Price Indexes for Intermediate Inputs (Bureau, 2014).

Monte Carlo Results

Monte Carlo simulations are repeated random samplings to obtain numerical stochastic or probabilistic results that assist with estimating risk and projections (Charnes, 2010). One Thousand Monte Carlo simulations were performed on the incremental cashflow model by varying the input variable of initial price of reclaimed water, Figure 16. The price of reclaimed water was chosen because it is likely more variable, due to being a market price, and because it has the most influence on this project's net present value, Table 21 and Figure 10.

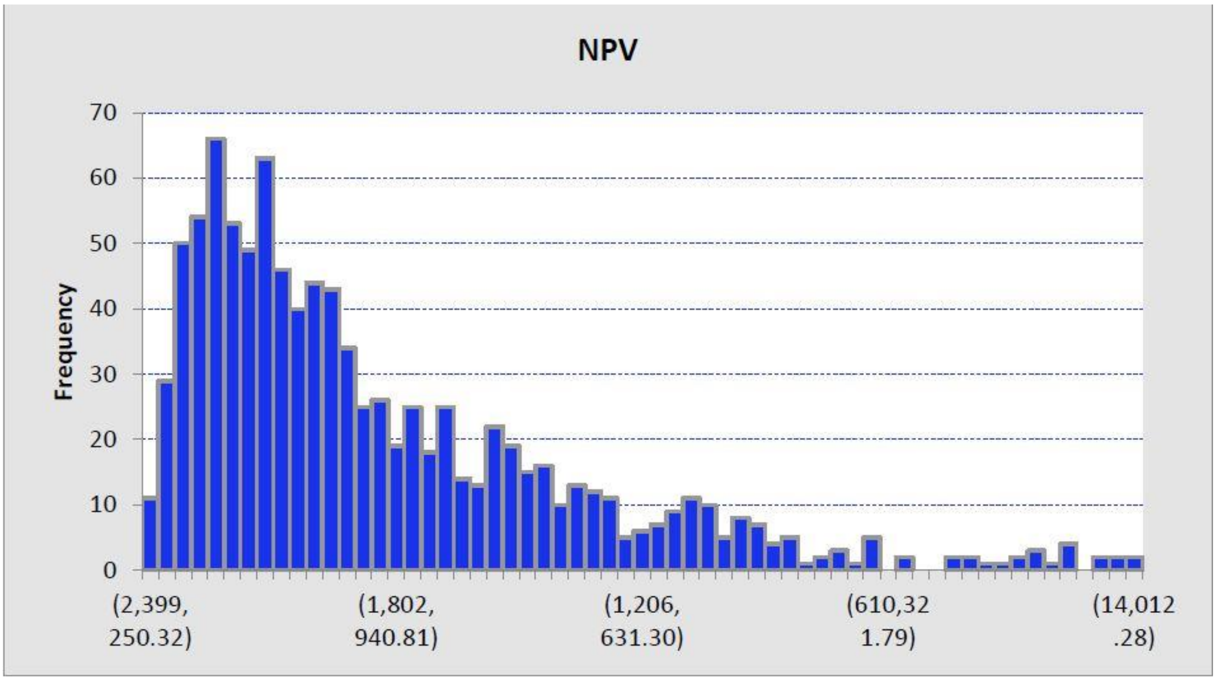


Figure 16: The distribution of net present value (NPV) resulting from 1,000 Monte Carlo simulations of the base-minimum reclaimed water demand scenario by varying the initial price of reclaimed water per gallon from the base of $0.00206 per gallon in 2014 nominal dollars. The X axis is in 2015 nominal dollars and parentheses represent negative values. The distribution of the initial reclaimed water per gallon price was assumed to be log-normally distributed. The mean= -1,787,613, median =- 1,985,662, standard deviation= 640,528, and the coefficient of variability = -0.3583.

Creation of the Bayesian Conceptual Model

Based on the interviews, a conceptual BNM was created, Figure 17. The driver is the reclaimed water usage projection and the Fishing Creek proximate discharge. The pressure is the ratio of treated water effluent over the total downstream discharge. There are 11 environmental state nodes covering the water quality and quantity. For environmental impacts, North Carolina Index of Biotic Integrity (NCIBI), Benthos bioclassification, algae productivity, and macrophytes are considered, which all point to the final output node of 'stream ecosystem health'. NCIBI, was developed for assessing a stream`s biological integrity by examining the structure and health of its fish community, which incorporates information about species richness and composition, pollution indicator, trophic composition, fish abundance, and fish condition (NC DWQ, 2013; NC DWQ, 2006). The NC DENR, Division of Water Quality (DWQ), has a Biological Assessment Branch which evaluates the water quality of streams using the biological communities that live in there (NC DWQ, 2006). The bio criteria within DWQ assessments has been developed using the diversity, abundance, richness, and pollution sensitivity of in-stream organisms. Five benthos or benthic macroinvertebrates bioclassifications are typically assigned to a water body in North Carolina. These are:

excellent, good, good-fair, fair, and poor. Both the fish community and benthos community could reflect long term and short term environmental conditions. Algae productivity is a good indicator for both nutrients and D.O. If nitrate and phosphorous concentrations are high, algae productivity increases dramatically, leading to sharp decreases in dissolved oxygen. Table 28 lists all the nodes from the conceptual model.

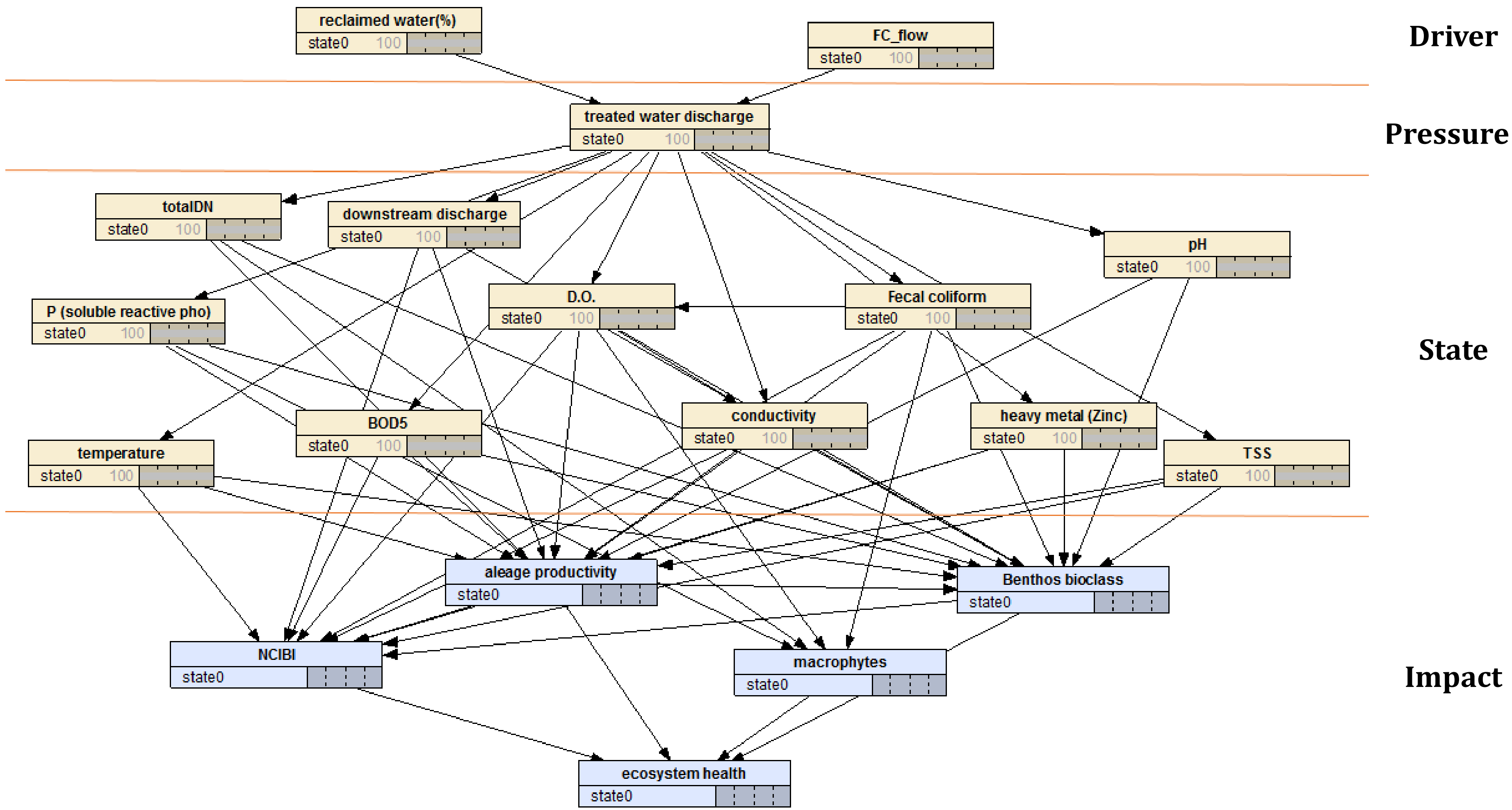


Figure 17: Conceptual Bayesian network model.

Table 28: Nodes chosen by experts to depict major system components in the Bayesian network.

Node name	Variable: units	DPSIR state
Reclaimed water	Reclaimed water usage: percentage of total discharge used for reclaimed water (%)	Driver
FC_flow	Fishing Creek natural flow near effluent site: mgd	
Treated water/downstream flow	The percentage of treated water effluent out of total downstream flow (%)	Pressure
TD-Nitrate	Total dissolved nitrate: mg/L	State
BOD5	BOD5 concentration: 20 DEG.C, mg/L	
P	Soluble reactive Phosphorus: mg/L	
DO	Dissolved oxygen concentration: mg/L	
Temperature	Temperature changes: degree C	
pH	pH changes: standard units	
TSS	Total suspend solid, or turbidity, mg/L	
Heavy metal (Zinc)	Zinc concentration, $\mu g/L$	
Conductivity	Water conductivity, uS	
Fecal coliform	Fecal coliform concentration: per 100ml	
Algae coverage	Algae coverage: g/m2	
Fish richness	NCIBI criteria metric: number of species	Impact
Fish abundance	NCIBI criteria metric: number of fish	
NCIBI	Examining health and structure of fish community, discrete scale of 4 levels, good, good-fair, fair, poor	
Benthos abundance	Bioclassification criteria: # of benthos per square meter	
Benthos richness	Bioclassidicaiton criteria: # of benthos species genera	
Bioclassification	Categories community composition and diversity: good, fair and poor	

Definition of states and scale for each node

After interviews with stream ecologists, it was concluded that the effluent water quality was quite good based on the analysis of pH, temperature, fecal coliform, and NH3-N and therefore these parameters were not important state variables for the stream ecosystem impact analysis or BNM. However, the dissolved oxygen (DO), zinc concentration, and BOD5 were considered as important state variables due to their levels.

Based on the conceptual Bayesian network, effluent water quality, and data availability, two concise conceptual models were created. All the scales were determined by standards, criteria and experts recommendations. Table 29 lists all the variables included and their states:

Table 29: States and scales for each node in the Bayesian network.

Nodes	State 1	State 2	State3
FC_flow	High (>6 mgd)	Moderate (2-6 mgd)	Low (<2 mgd)
D.O. concentration	Good (8-14 mg/L)	Fair (5-8 mg/L)	Poor (<5 mg/L)
Zinc concentration	Low (<30 mg/L)	Moderate (30-50)	High (50-120 mg/L)
Treated water/down stream flow	High (49-100%)	High moderate (20-49%)	Moderate (<20%)
Fish richness	High (15-30)	Moderate (10-15)	Low (<10)
Fish abundance	High (224-723)	Moderate (150-224)	Low (<150)
Benthos richness	High (30-50)	Medium (10-30)	Low (<10)
Benthos abundance	High (300-500)	Medium (100-300)	Low (<100)
Bioclassification	Good	Fair	Poor
NCIBI	Good (46-60) Good-fair (40-46)	Fair (34-40)	Poor (<34)

Conditional Probability Table based on experts' opinion

Based on the conceptual BNM, states of each node and their scales are defined, and conditional probability tables (CPT) are created. Table 30 depicts an example of CPT, and the others are listed in the questionnaire in the Appendix.

Table 30: Example of CPT: The effect of zinc concentration and dissolved oxygen on fish abundance.

If D.O. is... (mg/L)	If Zinc is... (ug/L)	Fish abundance will be ...		
		High (224-723)	Moderate (150-224)	Low (<150)
Good (8-14)	Low (0-30)	0.8	0.2	0.
Good (8-14)	Moderate (30-50)	0.75	0.2	0.05
Good (8-14)	High (>50)	0.5	0.3	0.2
Fair (5-8)	Low (0-30)	0.75	0.2	0.05
Fair (5-8)	Moderate (30-50)	0.6	0.3	0.1
Fair (5-8)	High (>50)	0.5	0.3	0.2
Poor (<5)	Low (0-30)	0.4	0.4	0.2
Poor (<5)	Moderate (30-50)	0.25	0.4	0.35
Poor (<5)	High (>50)	0.2	0.3	0.5

Quantification of the Bayesian Network Model

The BNM was quantified based on the selected nodes, their scales, and conditional probability tables. After modification and testing, the application of Bayesian network model was depicted in Figure 18 and Figure 19. The model indicates that when Fishing Creek is experiencing a wet season and the reclaimed water scenario base-minimum is selected, there is 66.2% probability that the NCIBI score is in a good state and 3.1% in a poor state. When Fishing Creek is experiencing a dry season and if reclaimed water scenario maximum is selected, then there is 70.3% probability that bioclassification is in good state and 12.3% probability in a poor state. Table 31 and Table 32 above list all the final results for NCIBI and bioclassification probability distributions. In wet and normal season, all the bioclassification have more than 70% probability in good state, and all the NCIBI have more than 63% probability in good state. Therefore, in wet and normal, all the reclaimed water scenarios do not have a high probability of negative impacts on the fish and benthos community.

During dry season, the maximum reclaimed water demand scenario has a slightly higher probability of a good state for both NCIBI and bioclassification, followed by the high reclaimed water demand scenario. In a dry season, the base-minimum and medium reclaimed water demand scenarios have a slightly lower probability of being in a good state according to their NCBIB and bioclassification, but the probabilities are still high. Therefore, all four scenarios within a dry season will likely have a low probability of negative impact on the stream ecosystem, however the reclaimed water demand scenarios of high and maximum have the highest probabilities of the Fishing Creek system being in a good state as measured by the NCBIB and macroinvertebrate bioclassification .

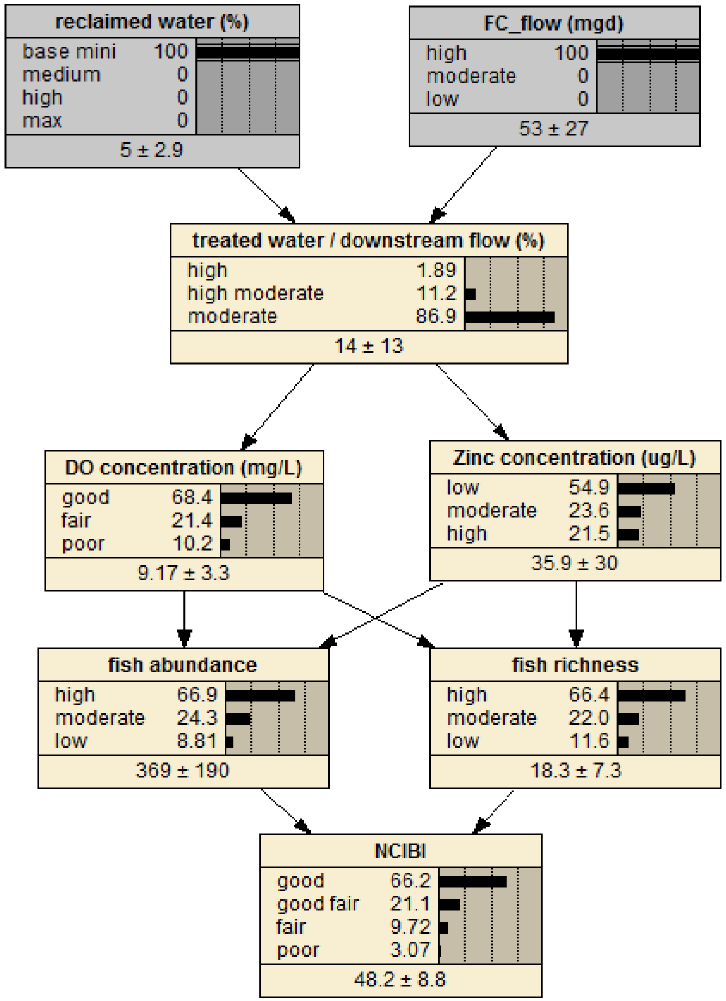


Figure 18*:* One example of the Bayesian network model for fish community.

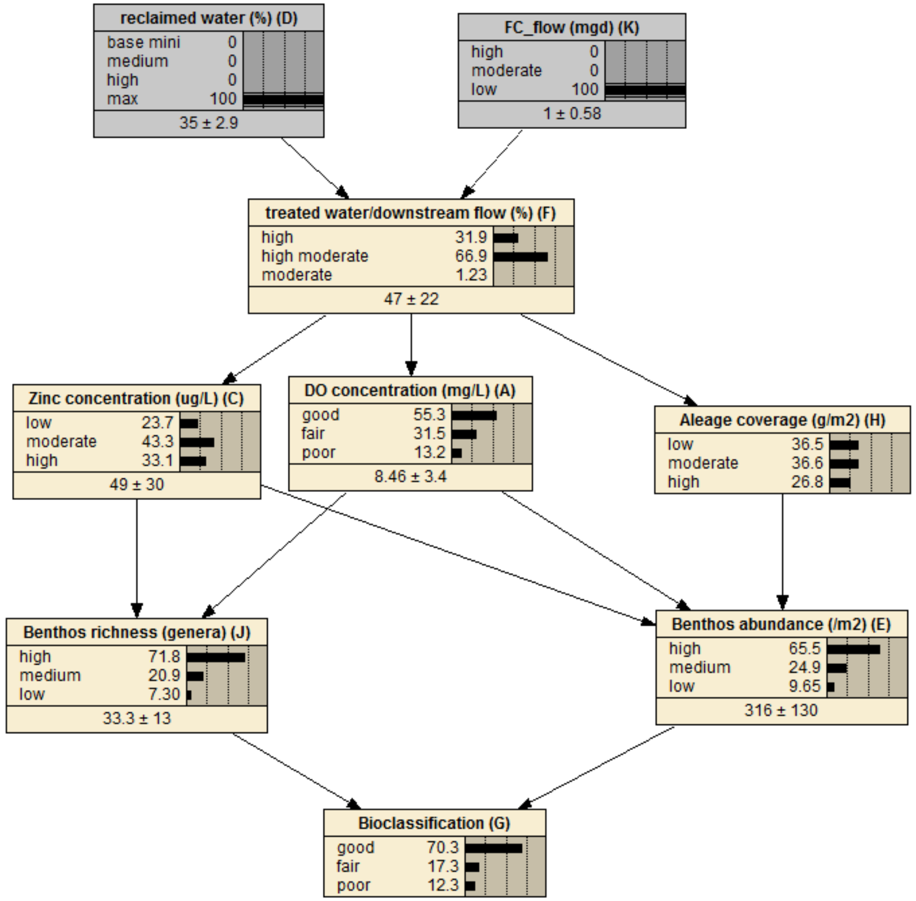


Figure 19: One example of the Bayesian network model for macroinvertebrate bioclassification.

Table 31: Bayesian network model results for the fish community

		Scenario1 Base-Minimum	Scenario2 Medium	Scenario3 High	Scenario4 Maximum
Fish	**Wet season**	NCIBI good 66.2 good fair 21.1 fair 9.72 poor 3.07 48.2 ± 8.8	NCIBI good 66.4 good fair 21.0 fair 9.64 poor 3.02 48.3 ± 8.8	NCIBI good 66.5 good fair 20.9 fair 9.60 poor 3.00 48.3 ± 8.8	NCIBI good 66.5 good fair 20.9 fair 9.59 poor 3.00 48.3 ± 8.8
	Normal season	NCIBI good 63.5 good fair 22.2 fair 10.7 poor 3.64 47.8 ± 9.2	NCIBI good 63.6 good fair 22.1 fair 10.6 poor 3.60 47.8 ± 9.1	NCIBI good 64.4 good fair 21.8 fair 10.4 poor 3.45 47.9 ± 9.1	NCIBI good 65.1 good fair 21.5 fair 10.1 poor 3.29 48 ± 9
	Dry season	NCIBI good 61.2 good fair 22.9 fair 11.7 poor 4.24 47.3 ± 9.5	NCIBI good 61.5 good fair 22.8 fair 11.5 poor 4.16 47.4 ± 9.5	NCIBI good 61.6 good fair 22.8 fair 11.5 poor 4.12 47.4 ± 9.4	NCIBI good 62.1 good fair 22.6 fair 11.3 poor 3.98 47.5 ± 9.4

Table 32: Bayesian network model results for macroinvertebrates classification.

		Scenario1 Base-Minimum	Scenario2 Medium	Scenario3 High	Scenario4 Maximum
Benthos	Wet season	Bioclassification (G) good 73.1 fair 15.3 poor 11.5	Bioclassification (G) good 73.3 fair 15.2 poor 11.4	Bioclassification (G) good 73.3 fair 15.1 poor 11.4	Bioclassification (G) good 73.3 fair 15.1 poor 11.4
	Normal season	Bioclassification (G) good 71.5 fair 16.5 poor 11.9	Bioclassification (G) good 71.6 fair 16.4 poor 11.9	Bioclassification (G) good 72.0 fair 16.1 poor 11.7	Bioclassification (G) good 72.5 fair 15.8 poor 11.6
	Dry season	Bioclassification (G) good 69.3 fair 17.8 poor 12.7	Bioclassification (G) good 69.6 fair 17.7 poor 12.6	Bioclassification (G) good 69.8 fair 17.6 poor 12.5	Bioclassification (G) good 70.3 fair 17.3 poor 12.3

CONLUSIONS & DISCUSSION

Based on this study's analysis of the water quality data available for the years 2012-2014, the water quality of Oxford's WWTP effluent is quite good compared to the NPDES permit standards, Table 2. There were only three one-time water quality standard noncompliance instances in the entire three year data-set. These were: the monthly average ammonia, the weekly cyanide average, and the dissolved oxygen (DO) concentration standard. Given these one-time non-compliance events it is reasonable to conclude that the WWTP effluent is of high quality concerning the WWTP's NPDES permit.

Despite a high frequency of compliance with the NPDES permit standards over a three year period, zinc and oxygen concentrations in the WWTP effluent may be of concern for the Fishing Creek ecosystem downstream of the WWTP outfall especially during summer or dry months. The zinc concentrations in the WWTP effluent were commonly above the freshwater aquatic life standard of 50 ug/L and the human health class C water standard of 36 ug/L, Figure 3 (Division of Water Quality 2015; North Carolina Administrative Code 2013). However, by adding the WWTP effluent to Fishing Creek natural streamflow, the effluent may be diluted enough so that Fishing Creek zinc concentrations are below state standards. Without accurate Fishing Creek discharge data, the degree of dilution and therefore compliance is unknown. However, the risk of zinc toxicity may be low according to Brix et al. (2010) who found that comparable zinc concentrations in stormwater had a relatively limited risk on bioavailability, exposure duration, and aquatic community composition. For a detailed review of the effects of WWTP effluent zinc toxicity see Mendelsohn, Chien-Hale, and Ding (2015). Similarly, the effects of WWTP effluent dissolved oxygen concentration below 8 mg/L on Fishing Creek are unknown. The recommended concentration for dissolved oxygen for in-stream biota is 8 mg/L (Hinton & Voss, pers. comm. Table 19).

Based on the model results of this study, we recommend that the City of Oxford move to maximize the amount of reclaimed water used if the City decides to build a reclaimed water system. Maximizing the amount of reclaimed water used increases the economic benefit and probability of the Fishing Creek ecosystem being in a 'good' state as defined by the NC DENR metrics of North Carolina Index of Biotic Integrity (fish assessment) and bioclassification of macroinvertebrates in both wet and dry periods based on WWTP effluent discharge, zinc, and dissolved concentrations, Table 33. Before a reclaimed water system is constructed, we recommend the City of Oxford and Granville County conduct a more in depth market study of potential reclaimed water users and demand (AWWA, 2009). A more in depth study would make for better estimations of reclaimed water demand and in turn the economic and environmental benefits.

Table 33: Environmental impact and economic value results of the Bayesian network and incremental cash flow models. Net present value (NPV) is represented in 2015 nominal dollar amounts. Environmental Value is measured as the probability of a 'good' state as measured by the average of North Carolina Department of Environment and Natural Resources metrics of North Carolina Index of Biotic Integrity and

bioclassification of macroinvertebrates based on WWTP effluent discharge, zinc, and dissolved concentrations.

		Scenario 1 Base-Minimum	Scenario 2 Medium	Scenario 3 High	Scenario 4 Maximum
Environmental Value	Wet & Normal Season	+++	+++	+++	+++
	Dry Season	+	+	++	++
Economic Value	NPV	-1,804,008	-1,683,525	-1,563,043	-1,422,560

+ = good state 50-65.5% probability

++ = good state greater than 65.5% probability

+++ = good state greater than 67.5% probability

If the City of Oxford builds a reclaimed water system, we recommend Oxford decision makers should maximize the price of reclaimed water per gallon as a % of the potable rate and the percentage of reclaimed water revenue generated from fixed fees, Table 22, Table 23 and Figure 10, Figure 11. Table 21 identifies the prices per gallon of reclaimed water that Oxford could charge for the four reclaimed water demand scenarios to set the reclaimed water project's net present value to zero. Only the medium, high, and maximum scenario prices are realistic for Oxford given their respective percentages of drinking water price. We recommend Oxford attempt to find enough reclaimed water demand to meet the medium demand scenario and if that demand is found, to charge, at a minimum, $2.71 per 1000 gallons.

Economic Model Limitations

The NPV of the reclaimed water project across the four reclaimed water demand scenarios is more than negative $1 million dollars. Figure 16 illustrates the distribution of NPV, which is mainly negative, from the base-minimum demand scenario by varying the price of reclaimed water with Monte Carlo simulations. However, there are economic benefits that are not quantified in this study's incremental cashflow model which may offset these negative values and even make the net present value positive. The National Research Council of the National Academies report on water re-use (2012) identifies several economic benefits to water reclamation which include: improved water source reliability, improved community self-sufficiency, community environmental awareness, local economic vitality, increased water for the environment, and improved surface water quality. Another economic benefit to water reclamation is foregone or delayed infrastructure costs for potable water.

We believe that increased water source reliability, improved surface water quality, and foregone potable water infrastructure costs are the most relevant non-monetized economic benefits of water reclamation for the City of Oxford. Water reclamation in Oxford would increase non-potable water source reliability, and it would be especially valuable during times of drought. If drought restrictions on potable water did occur, the value of un-restricted reclaimed water for non-potable uses would increase, but it is unknown how much that increase would be. The value of water reclamation in Oxford during drought may also be higher because it would lessen the negative environmental impact on the Fishing Creek ecosystem by reducing inputs of potentially low dissolved oxygen and high zinc concentrations, Figure 2 and Figure 3, during dry periods.

If enough water was reclaimed in Oxford, water reclamation could cause foregone or delayed potable water demand and the need for associated potable water infrastructure improvement and expansion costs. The City of Oxford's Water and Wastewater 30-year Master Plan outlines the need to build new water mains, elevated storage tanks, and booster stations for the Triangle North Industrial Park, Stovall Water Line, and I-85 Exit 202 (West 2010). The 30 year Master Plan's outlook is until 2039, and it does not identify when improvements to Oxford's water system are needed, but only that improvements are likely between 2010 and 2039. The City of Oxford recently approved the construction of a 500,000 gallon elevated storage tank in its proposed 2014-2015 Budget which is estimated to cost $139,200 (City of Oxford, 2015). If reclaimed water usage can offset potable water usage for non-potable purposes so that some portion of potable water infrastructure costs are foregone or delayed, the benefits could be significant.

In addition to un-quantified economic benefits, the reclaimed water system may have associated non-monetized economic costs that are not incorporated in this study's incremental cash flow model. The National Research Council (2012) identifies several economic costs which may include: increased greenhouse gas emissions, public health effects, public perception of reduced drinking water quality, water quality impacts at sites of reclaimed water usage, effects on soils and plants, and effects on downstream flows. The effect of reclaimed water on public health in North Carolina would likely be minimal given that state regulations require adequate signage, recommended irrigation rates, and specific uses for reclaimed water (North Carolina Administrative Code, 2011). Environmental effects on plants, soils, and water quality, based on our analysis of 2012-2014 WWTP effluent water quality, would likely be minimal. Mendelsohn, Chien-Hale, and Ding (2015) found that the comparison of effluent toxicant concentrations with worst-case dose scenarios for common terrestrial species indicate a very low risk associated with the City of Oxford WWTP effluent. Water reclamation would affect downstream flows in Fishing Creek and the Tar River, however we assume these effects to be minimal given North Carolina is a riparian water rights state which allows beneficial uses to impact downstream users to some extent. There are also no nearby major water intakes downstream of the WWTP outfall. The effect reclaimed water would have on net GHG emissions and the cost of public perception of reduced water quality are two areas of potential further research.

Environmental Model Limitations

The Bayesian network model (BNM) results assume that Reed's Creek discharge data, a nearby stream to Fishing Creek, is a reasonable approximation for Fishing Creek discharge, due to its similar watershed area and proximity. However, given that discharge is an important input variable to the BNM because WWTP effluent pollutants are potentially diluted by creek discharges, actual discharge data for Fishing Creek would enhance the accuracy of model estimations of 'good' state probabilities, as measured by zinc and dissolved oxygen concentrations and defined by the NC DENR metrics of NCIBI score (a fish based index) and bioclassification of macroinvertebrates.

The BNM would also better estimate the probabilities of the Fishing Creek ecosystem with more robust water quality, fish, and macroinvertebrate data. In particular, a more robust water quality data-set, upstream and downstream of the WWTP outfall, would allow us to modify and improve the BNM by incorporating more than just expert opinion and limited data. Further research on the Fishing Creek ecosystem using BNM should focus on gathering this on-site data.

The testing of the WWTP effluent for more water quality parameters such as carcinogens and other toxicants would allow us to create a BNM with more variants of the state of the Fishing Creek ecosystem besides zinc and dissolved oxygen states. Similarly, leachate from the Granville County Landfill, which is accepted and treated by the Oxford WWTP, should be tested for additional toxicants. Kjeldsen et al. (2010) suggest four categories of leachate contaminants that could be tested for: dissolved organic matter (quantified as chemical oxygen demand or total organic carbon), inorganic macro components (ions such as calcium, magnesium, sodium, potassium, ammonium, iron, manganese, chloride, sulfate, and hydrogen carbonate), heavy metals (cadmium, chromium, copper, lead, nickel, and zinc), and xenobiotic organic compounds (household chemicals such as aromatic hydrocarbons, phenols, chlorinated aliphatics, pesticides, and plasticizers). For a detailed analysis of the risks of Granville County Landfill leachate toxicity see Mendelsohn, Chien-Hale, and Ding (2015). In general, organic pollutants have not been considered to date.

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APPENDIX

A. WWTP effluent water quality

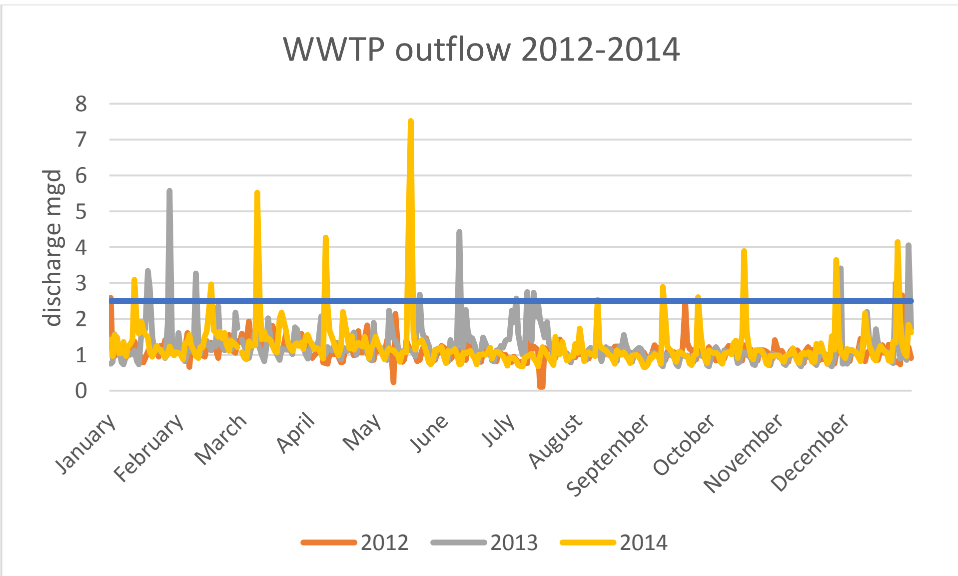


Figure 20: WWTP outflow from 2012-2014. The blue line represents a discharge threshold of 2.5 MGD. Discharges greater than 2.5 MGD are considered to be caused by excessive rainfall (Wilson, 2014, pers. comm.)

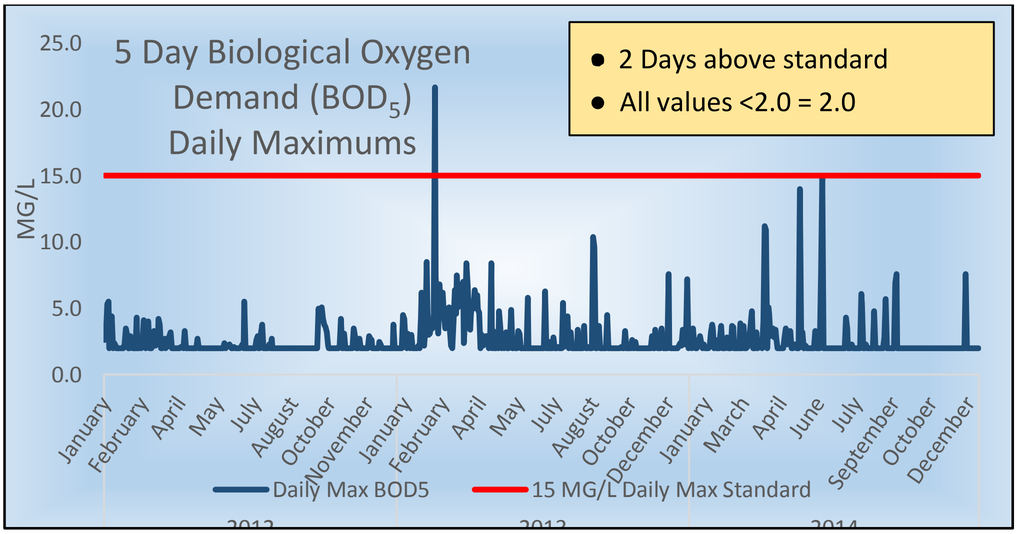


Figure 21: City of Oxford wastewater treatment plant's effluent daily 5 day biological oxygen demand (BOD_5) concentrations from 2012-2014. The North Carolina reclaimed water type I standard for daily maximum BOD_5 is 15 mg/L and is provided for reference.

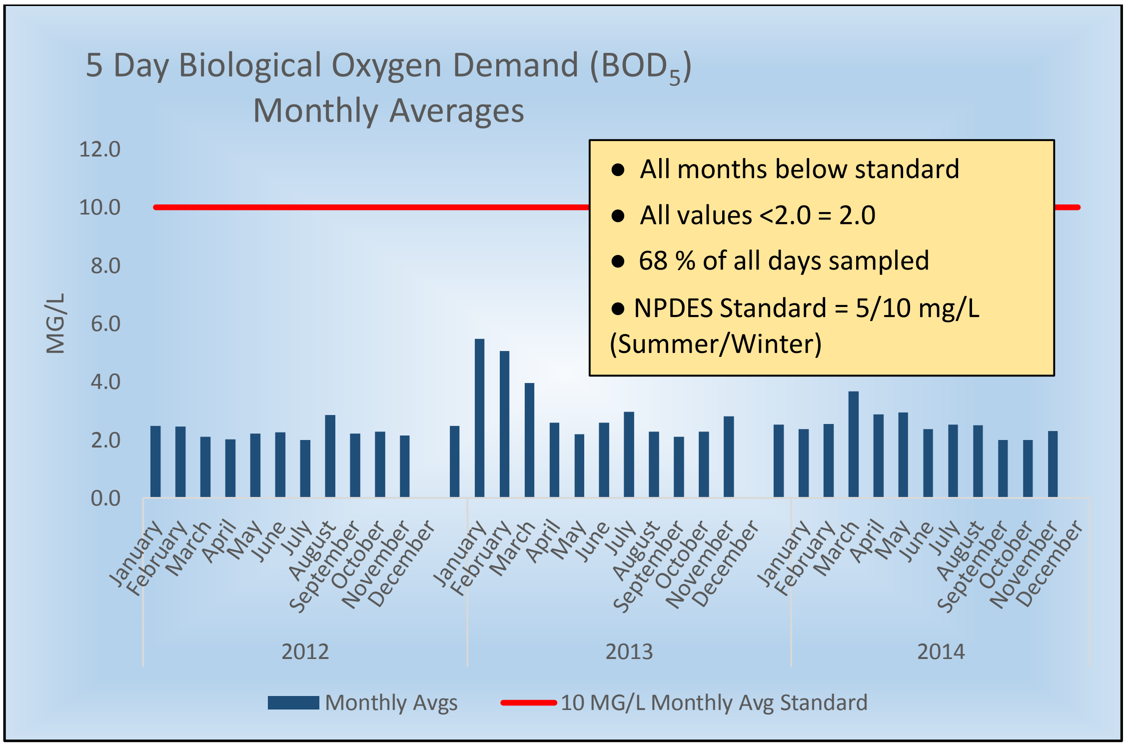


Figure 22: City of Oxford wastewater treatment plant's effluent monthly average 5 day biological oxygen demand (BOD_5) concentrations from 2012-2014. The North Carolina reclaimed water type I standard for monthly average BOD_5 is 10 mg/L and is provided for reference.

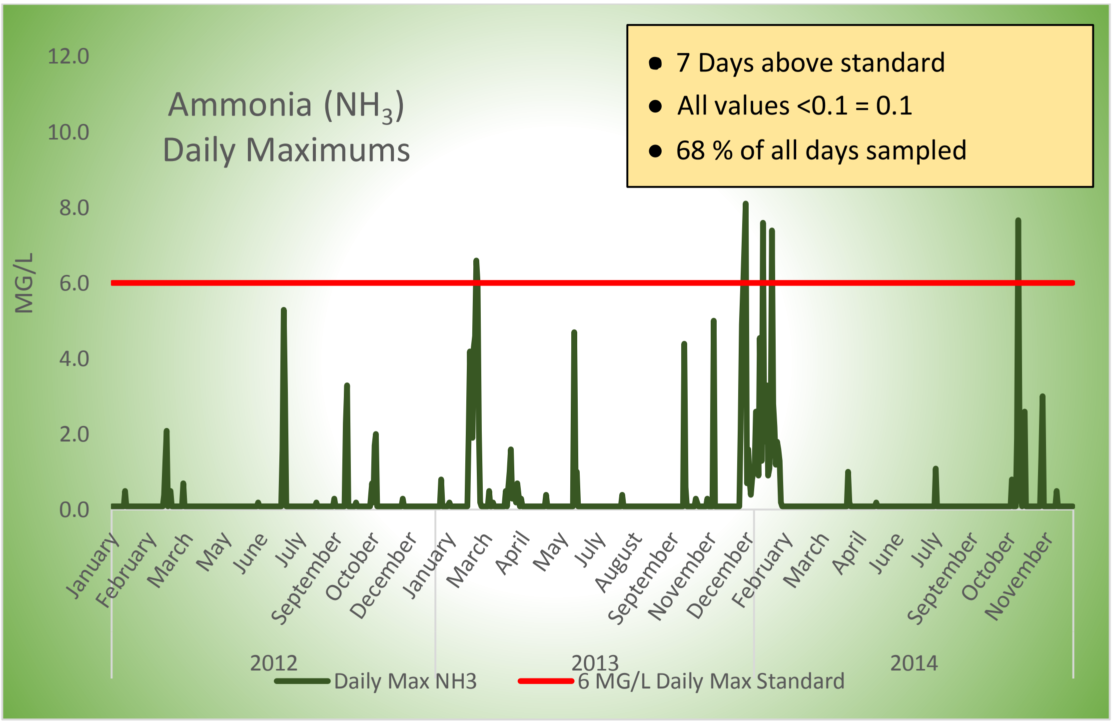


Figure 23: City of Oxford wastewater treatment plant's effluent daily maximum ammonia (NH_3) concentrations from 2012-2014. The North Carolina reclaimed water type I standard for daily maximum NH_3 is 6 mg/L and is provided for reference.

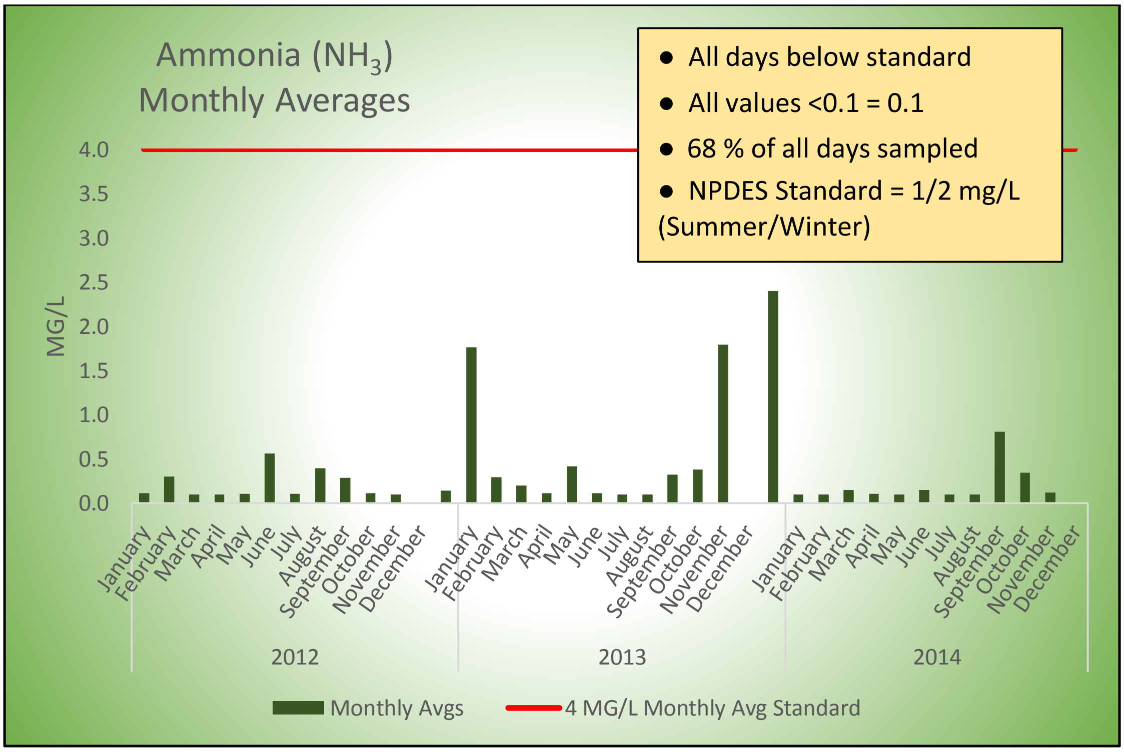


Figure 24: City of Oxford wastewater treatment plant's effluent monthly average ammonia (NH_3) concentrations from 2012-2014. The North Carolina reclaimed water type I standard for monthly average NH_3 is 4 mg/L and is provided for reference.

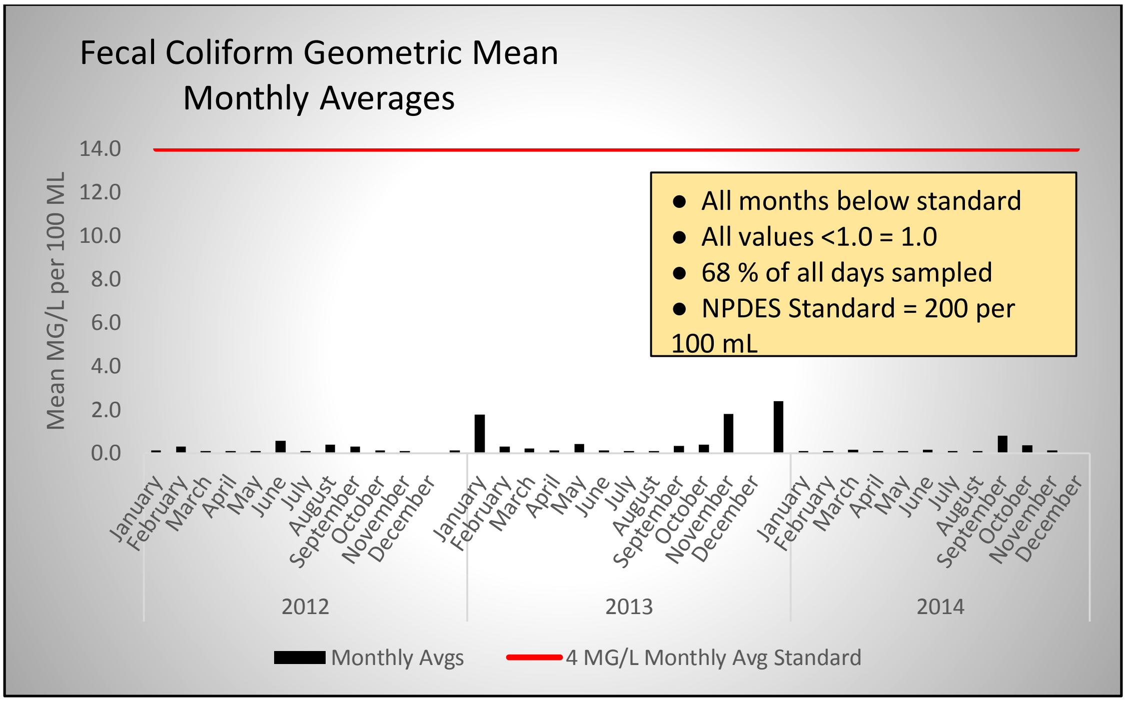


Figure 25: City of Oxford wastewater treatment plant's effluent monthly geometric mean fecal coliform concentrations from 2012-2014. The North Carolina reclaimed water type I standard for monthly geometric mean fecal coliform is 14 mg/L and is provided for reference.

B. Incremental cash flow model and inputs

Table 34: Base-Minimum Incremental Cash Flow Model.

NOMINAL CASH FLOW TO CITY OF OXFORD	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
CASH IN															
Reclaimed Water Revenues															
Cost Savings from Reduction in Bulk Water Purchase, Pumping, Treatment			22,334.81	23,581.33	24,897.42	26,286.96	27,754.05	29,303.02	30,938.44	32,665.14	34,488.20	36,413.00	38,445.24	40,590.89	42,856.29
Reclaimed Water Usage Revenue			13,104.73	13,494.68	13,896.24	14,309.74	14,735.55	15,174.02	15,625.55	16,090.51	16,569.31	17,062.35	17,570.06	18,092.89	18,631.27
Reclaimed Water Fixed Fee Revenue			13,104.73	13,494.68	13,896.24	14,309.74	14,735.55	15,174.02	15,625.55	16,090.51	16,569.31	17,062.35	17,570.06	18,092.89	18,631.27
Liquidation Values:															
Equipment and Route															
TOTAL CASH IN	1,027,573.94	0.00	48,544.28	50,570.70	52,689.90	54,906.44	57,225.15	59,651.07	62,189.54	64,846.16	67,626.81	70,537.70	73,585.37	76,776.66	80,118.83
CASH OUT															
Reclaimed water investments:															
Mobilization	14,511.64														
Submersible Pump	38,093.06														
100,000 Gallon Concrete Tank	181,395.50														
Chemical Feed and Pump Building	122,441.96														
8 inch Piping	18,139.55														
Sitework and Paving	27,209.33														
Chlorine Feed System	22,674.44														
Sodium Bicarbonate Feed System	22,674.44														
Plant Non-Potable Booster Pump Skid	63,488.43														
Reclaimed Water Distribution Skid	122,441.96														
Electrical and Controls	68,023.31														
SCADA	22,674.44														
Contingencies	72,558.20														
Engineering Design	61,521.87														
Construction Admin & Observation	43,944.19														
Grant Administration	26,366.51														
Easement Acquisition & Legal Fees	8,788.84														
Route (Avg of 5 Routes Cost)	1,118,200.22														
Reclaimed Water Operations															
Reclaimed Water Cost			42,445.36	44,461.97	46,579.05	48,801.79	51,135.67	53,586.44	56,160.17	58,863.25	61,702.41	64,684.73	67,817.68	71,109.13	74,567.36
Foregone Drinking Water Revenue			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Loan Expenses		45,634.07	45,634.07	45,634.07	45,634.07	45,634.07	45,634.07	45,634.07	45,634.07	45,634.07	45,634.07	45,634.07	45,634.07	45,634.07	45,634.07
TOTAL CASH OUT	2,055,147.87	45,634.07	88,079.43	90,096.04	92,213.12	94,435.86	96,769.74	99,220.51	101,794.24	104,497.32	107,336.47	110,318.80	113,451.75	116,743.19	120,201.42
NET CASH FLOW	(1,027,573.94)	(45,634.07)	(39,535.15)	(39,525.34)	(39,523.22)	(39,529.42)	(39,544.59)	(39,569.44)	(39,604.70)	(39,651.16)	(39,709.67)	(39,781.09)	(39,866.38)	(39,966.53)	(40,082.60)
NPV	(1,784,031.28)														

2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
45,248.13	47,773.45	50,439.72	53,254.79	56,226.97	59,365.03	62,678.23	66,176.34	69,869.69	73,769.16	77,886.26
19,185.67	19,756.56	20,344.45	20,949.83	21,573.22	22,215.16	22,876.21	23,556.92	24,257.89	24,979.72	25,723.03
19,185.67	19,756.56	20,344.45	20,949.83	21,573.22	22,215.16	22,876.21	23,556.92	24,257.89	24,979.72	25,723.03
83,619.46	87,286.58	91,128.62	95,154.45	99,373.41	103,795.36	108,430.65	113,290.19	118,385.47	123,728.59	129,332.31
78,201.09	82,019.53	86,032.37	90,249.80	94,682.59	99,342.06	104,240.17	109,389.49	114,803.28	120,495.52	126,480.94
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45,634.07	45,634.07	45,634.07	45,634.07	45,634.07	45,634.07	45,634.07	45,634.07	45,634.07	45,634.07	45,634.07
123,835.16	127,653.60	131,666.43	135,883.87	140,316.65	144,976.13	149,874.23	155,023.55	160,437.34	166,129.59	172,115.01
(40,215.70)	(40,367.02)	(40,537.82)	(40,729.42)	(40,943.24)	(41,180.77)	(41,443.59)	(41,733.37)	(42,051.88)	(42,400.99)	(42,782.69)

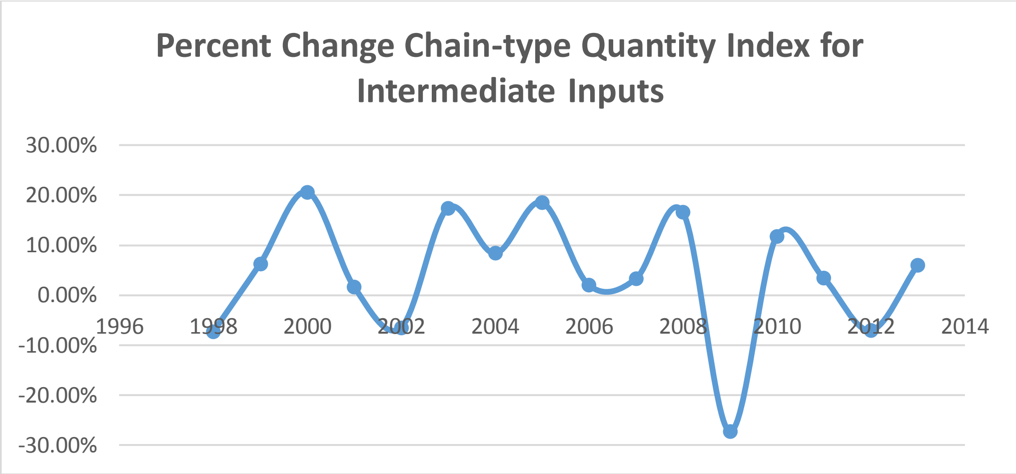


Figure 26: The percent change of the Chain-type Quantity Index for Intermediate Inputs from the U.S. Bureau of Economic Analysis (2014).

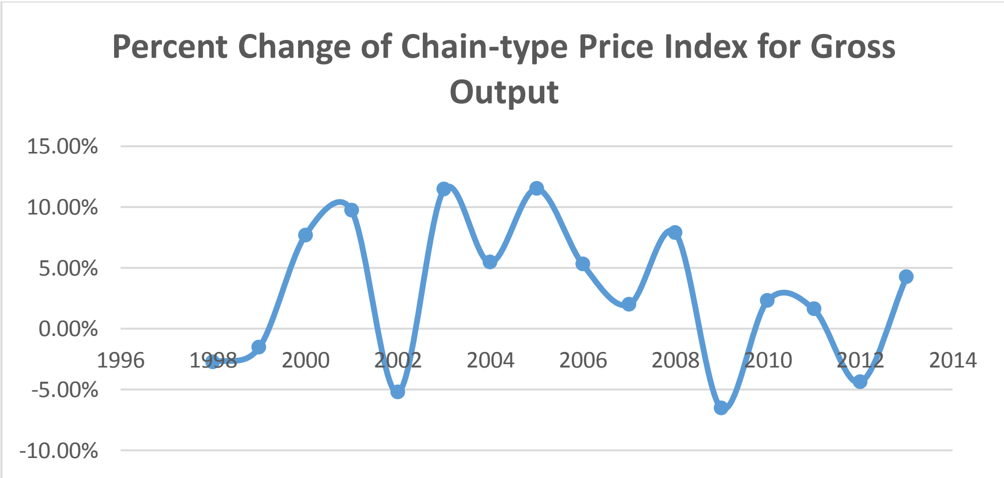


Figure 27: The percent change of the Chain-type Price Index for Gross Output from the U.S. Bureau of Economic Analysis (2014).

Table 35: The Town of Holly Springs fiscal year (FY) 2013-2014 items and calculation to arrive at the average cost of reclaimed water per gallon based on the proportion of reclaimed water revenues to total water and sewer fund revenues multiplied by total water and sewer fund expenditures. Debt service and interest revenue are subtracted prior to calculations.

Item	Cost FY 13-14	Comments
Reclaimed Water Used	74,149,410	Gallons
Reclaimed Water Rate	$ 3.75	per 1000 gallons
Reclaimed Water Sales	$ 278,060	Reclaimed Revenue if all gallons sold
Reclaimed Water other revenues	$ 21,927	Source FY 2014 Audit
Water & Sewer Fund Total Revenue	$ 9,765,758	Source FY 2013 Audit (less interest revenue)
Reclaimed Water Sales Reported	$ 71,471	
Water & Sewer Fund Total Revenue	$ 9,694,287	less reported sales
Water & Sewer Fund Debt Service	$ 4,077,856	Source FY 2014 Audit
Water & Sewer Fund Total Expense	$ 10,396,498	Source FY 2014 Audit
Water & Sewer Fund Expense Less Debt Service	$ 6,318,642	

Proportion Revenue/Total Revenue	0.030	Reclaimed Revenue/Total Revenue
Reclaimed Water Expense based on Proportion	$ 190,076.84	Water & Sewer Fund Expense * revenue proportion
Avg Cost of Reclaimed Water per gallon	$0.00256	2014 Dollars (Capital + O&M Cost)

Table 36: The Town of Holly Springs fiscal year (FY) 2012-2013 items and calculation to arrive at the average cost of reclaimed water per gallon based on the proportion of reclaimed water revenues to total water and sewer fund revenues multiplied by total water and sewer fund expenditures. Debt service and interest revenue are subtracted prior to calculations.

Item	Cost FY 12-13	Comments
Reclaimed Water Used	68,953,300	Gallons
Reclaimed Water Rate	$ 3.75	per 1000 gallons
Reclaimed Water Sales	$ 258,575	Reclaimed Revenue if all gallons sold
Reclaimed Water other revenues	$ 10,540	Source FY 2013 Audit
Water & Sewer Fund Total Revenue	$ 9,407,992	Source FY 2013 Audit (less interest revenue)
Reclaimed Water Sales in Budget	$ 68,705	
Water & Sewer Fund Total Revenue (less sales)	$ 9,339,287	
Water & Sewer Fund Debt Service	$ 4,626,471	Source FY 2013 Audit
Water & Sewer Fund Total Expense	$ 11,408,694	Source FY 2013 Audit
Water & Sewer Fund Expense Less Debt Service	$ 6,782,223	
Proportion Revenue/Total Revenue	0.028	Reclaimed Revenue/Total Revenue
Reclaimed Water Expense based on Proportion	$ 190,167.05	Water & Sewer Fund Expense * revenue proportion
Avg Cost of Reclaimed Water per gallon	$ 0.00276	2013 Dollars (Capital + O&M Cost)
Avg Cost of Reclaimed Water per gallon	$ 0.00290	2014 Dollars (Capital + O&M Cost)

Table 37: The Town of Holly Springs fiscal year (FY) 2011-2012 items and calculation to arrive at the average cost of reclaimed water per gallon based on the proportion of reclaimed water revenues to total water and sewer fund revenues multiplied by total water and sewer fund expenditures. Debt service and interest revenue are subtracted prior to calculations.

Item	Cost FY 11-12	Comments
Reclaimed Water Used	55,040,700	Gallons
Reclaimed Water Rate	$ 3.75	per 1000 gallons
Reclaimed Water Sales	$ 206,403	Reclaimed Revenue if all gallons sold
Reclaimed Water other revenues	$ 15,660	
Water & Sewer Fund Total Revenue	$ 9,550,280	Source FY 2013 Audit
Reclaimed Water Sales in Budget	$ 75,354	

Water & Sewer Fund Total Revenue (less sales)	$ 9,474,926	
Water & Sewer Fund Debt Service	$ 4,716,025	Source FY 2013 Audit
Water & Sewer Fund Total Expense	$ 10,430,804	Source FY 2013 Audit
Water & Sewer Fund Expense Less Debt Service	$ 5,714,779	
Proportion Revenue/Total Revenue	0.023	Reclaimed Revenue/Total Revenue
Reclaimed Water Expense based on Proportion	$ 131,081.06	Water & Sewer Fund Expense * revenue proportion
Avg Cost of Reclaimed Water per gallon	$ 0.00238	2012 Dollars (Capital + O&M Cost)
Avg Cost of Reclaimed Water per gallon	$ 0.00244	2014 Dollars (Capital + O&M Cost)

Table 38: The Town of Holly Springs fiscal year (FY) 2010-2011 items and calculation to arrive at the average cost of reclaimed water per gallon based on the proportion of reclaimed water revenues to total water and sewer fund revenues multiplied by total water and sewer fund expenditures. Debt service and interest revenue are subtracted prior to calculations.

Item	Cost FY 10-11	Comments
Reclaimed Water Used	61,799,000	Gallons
Reclaimed Water Rate	$ 3.75	per 1000 gallons
Reclaimed Water Sales	$ 231,746	Reclaimed Revenue if all gallons sold
Reclaimed Water other revenues	$ 2,558	
Water & Sewer Fund Total Revenue	$ 8,983,053	Source FY 2013 Audit
Reclaimed Water Sales in Budget	$ 34,157	
Water & Sewer Fund Total Revenue (less sales)	$ 8,948,896	
Water & Sewer Fund Debt Service	$ 4,024,344	Source FY 2013 Audit
Water & Sewer Fund Total Expense	$ 9,161,963	Source FY 2013 Audit
Water & Sewer Fund Expense Less Debt Service	$ 5,137,619	
Proportion Revenue/Total Revenue	0.026	Reclaimed Revenue/Total Revenue
Reclaimed Water Expense based on Proportion	$ 131,120.02	Water & Sewer Fund Expense * revenue proportion
Avg Cost of Reclaimed Water per gallon	$ 0.00212	2011 Dollars (Capital + O&M Cost)
Avg Cost of Reclaimed Water per gallon	$ 0.00226	2014 Dollars (Capital + O&M Cost)

Table 39: Reclaimed Water Operations and Maintenance costs from the National Research Council (2014) survey of national reclaimed water systems.

Facility	Durango Hills	Desert Breeze	Trinity River				
Location	Las Vegas, NV	Las Vegas, NV	Authority, TX	Denver, CO	West Basin, CA	Tucson, AZ	Inland Empire, CA
Capacity(MGD)	10	5	16.4	30	40	30	40
Average Output (MGD)	3	2.9	1	6	18	15.2	15.2
Average Output MG per year	1,095	1,059	365	2,190	6,570	5,548	5,548
Year Constructed	1999-2004	2001-2004	1987	2000-2012	1995-2006	1982+	2001-2010
O & M Costs ($/gal)							
Labor	0.07	0.05	0.01	0.54	0.2	0.13	1
Energy	0.36	0.21	0.01	0.19	0.22	0.25	0.18
Other	0.25	0.09	0.03	0.33	0.6	0.12	0
Total $/kgal (2009 Dollars)	0.68	0.35	0.05	1.06	1.02	0.5	1.18
Total $/gal (2009 Dollars)	0.00068	0.00035	0.00005	0.00106	0.00102	0.00050	0.00118
Total $/gal (2014 Dollars)	0.00062	0.00032	0.00005	0.00104	0.00094	0.00047	0.00122

C. Reclaimed Water Routes

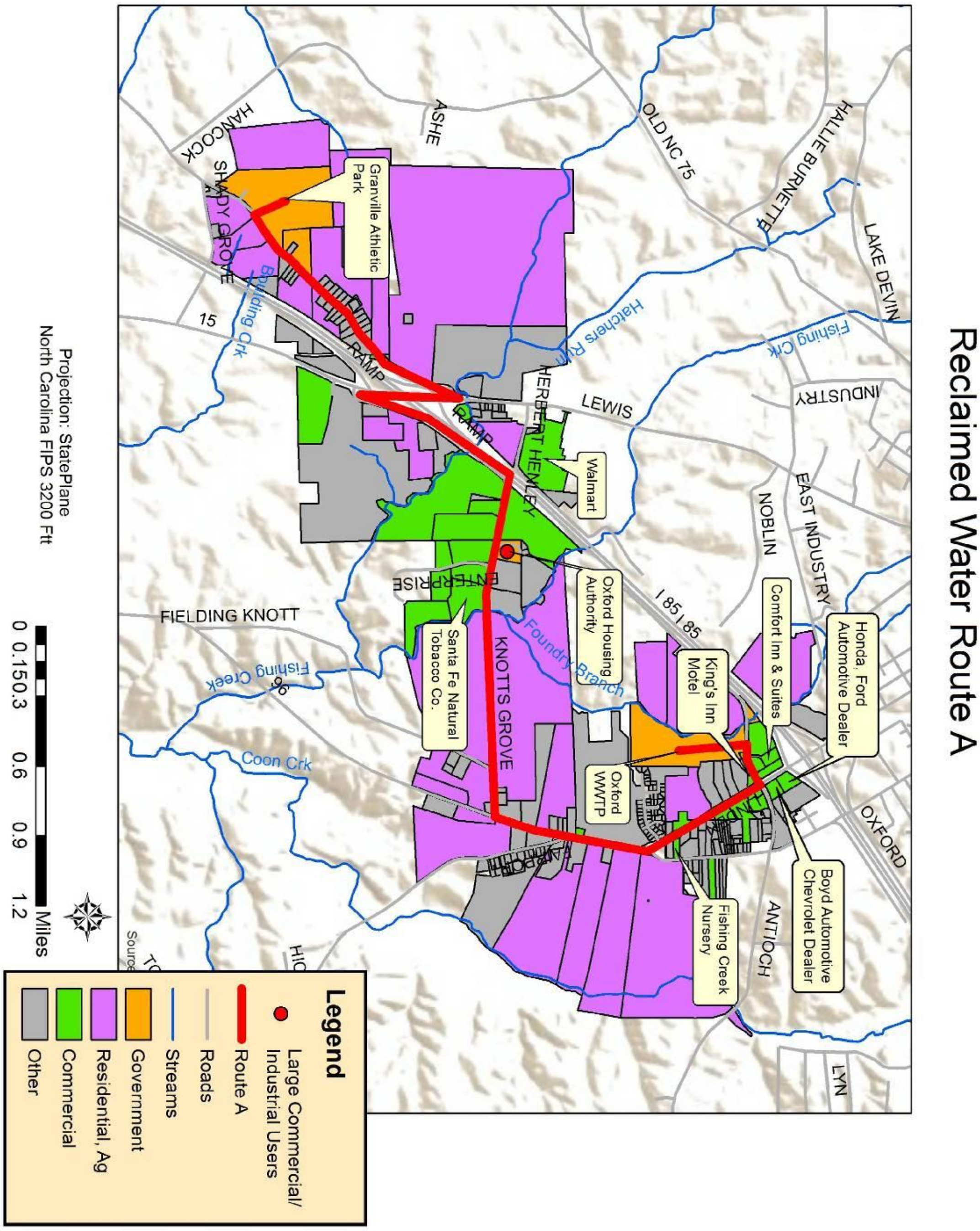


Figure 28: Reclaimed water pipe route A as found in the Reclaimed Water System Study (McGill 2010). Land parcels within 1000 feet are identified and classified.

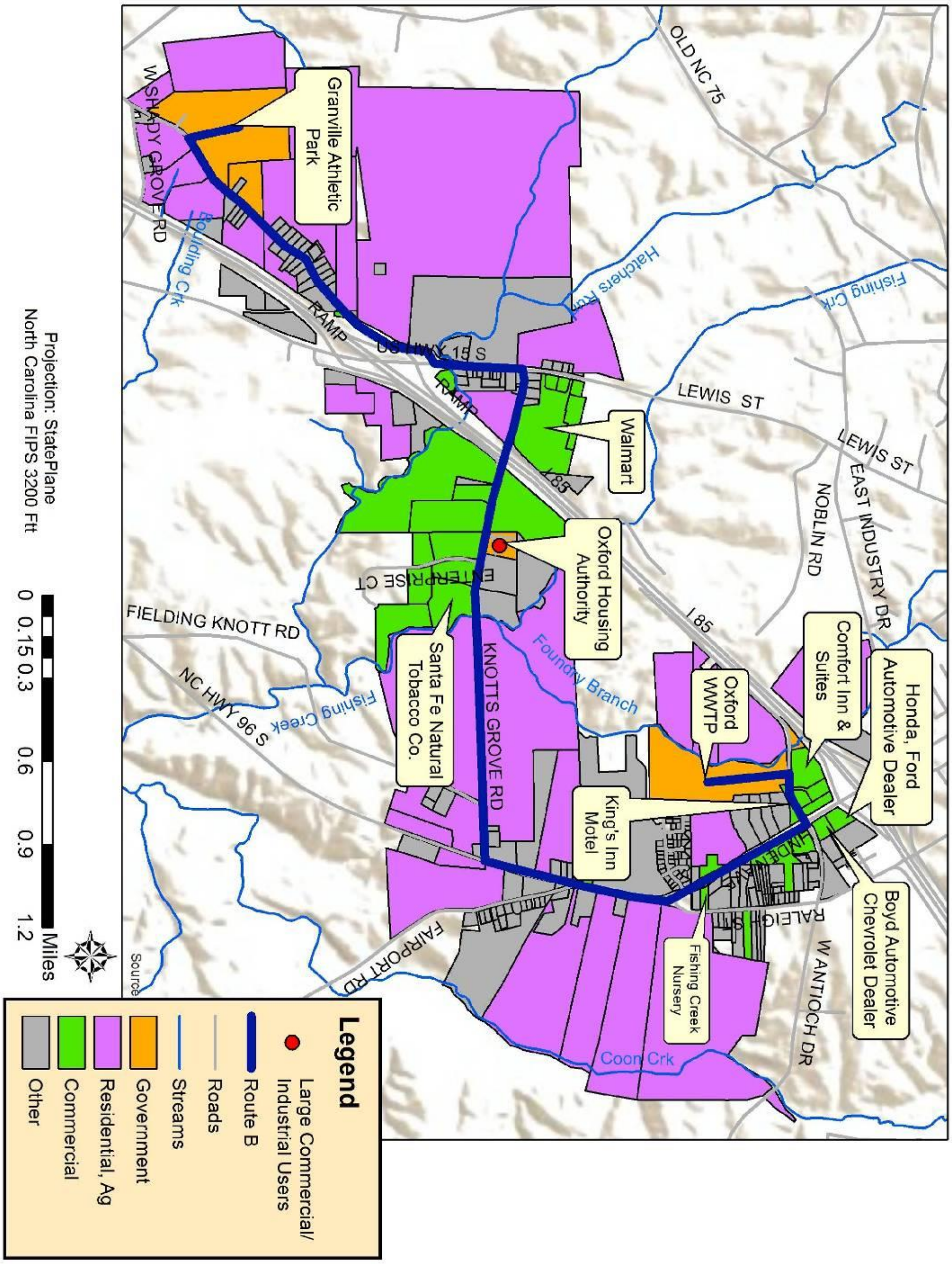


Figure 29: Reclaimed water pipe route B as found in the Reclaimed Water System Study (McGill 2010). Land parcels within 1000 feet are identified and classified.

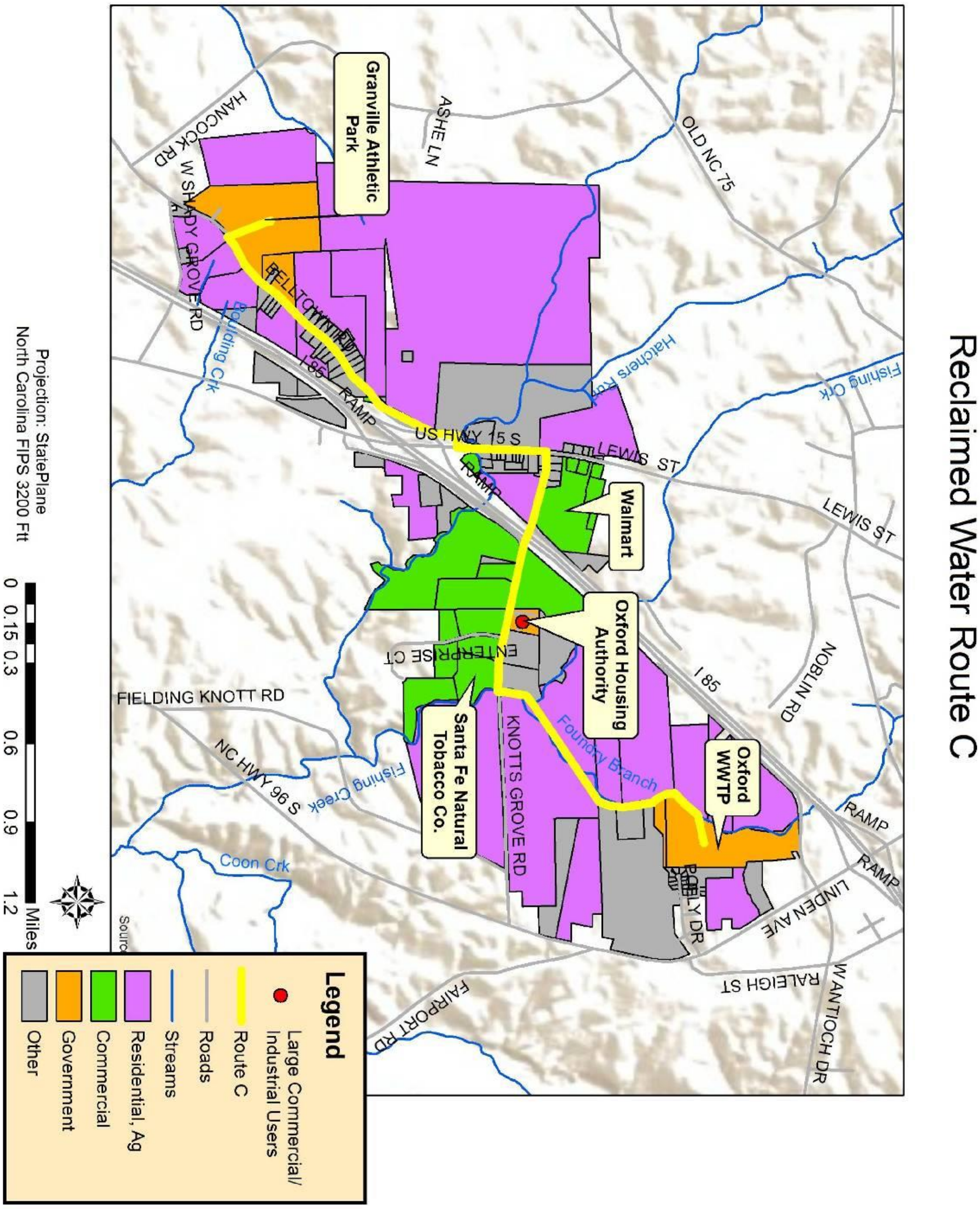


Figure 30: Reclaimed water pipe route C as found in the Reclaimed Water System Study (McGill 2010). Land parcels within 1000 feet are identified and classified.

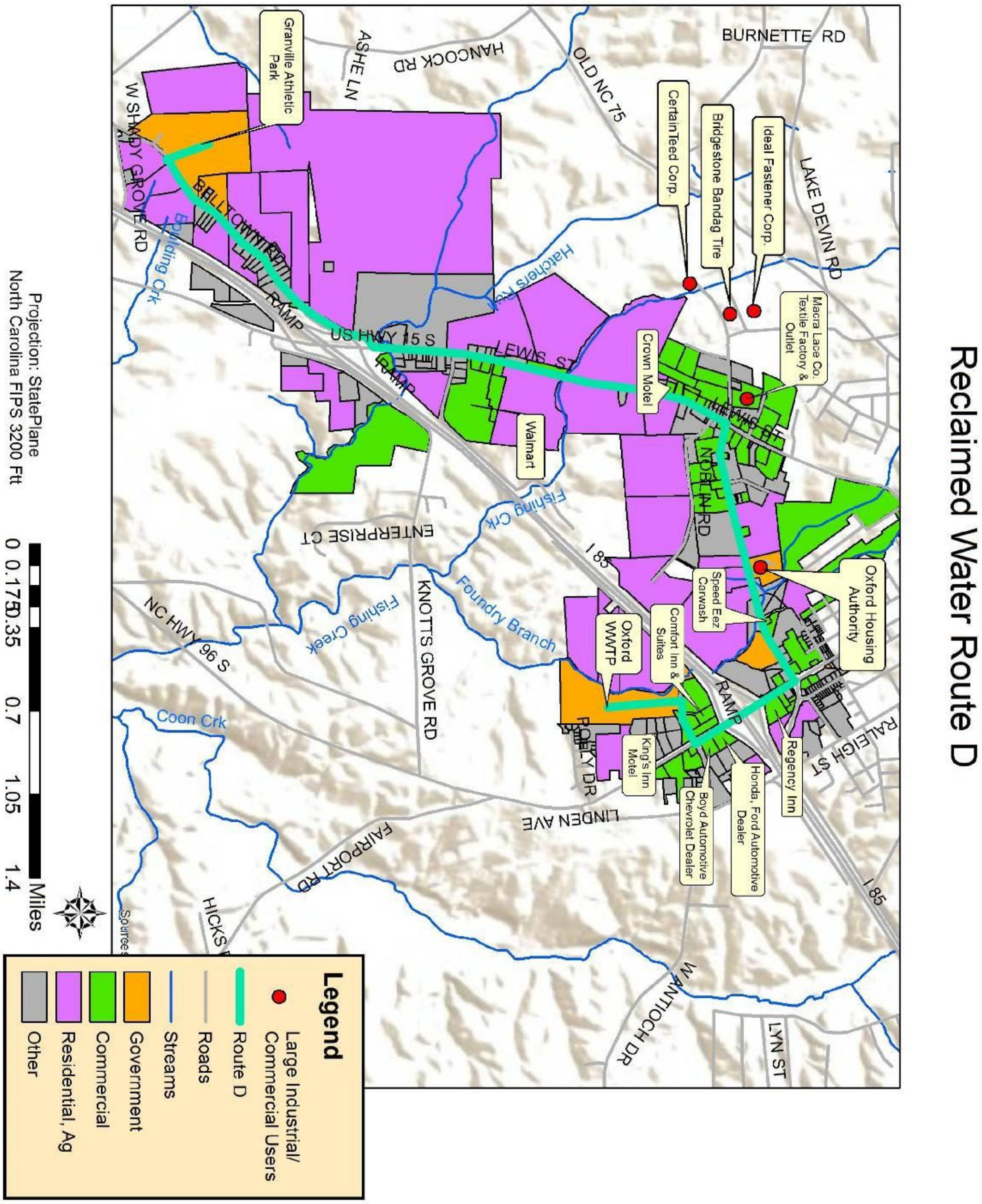


Figure 31: Reclaimed water pipe route D as found in the Reclaimed Water System Study (McGill 2010). Land parcels within 1000 feet are identified and classified.

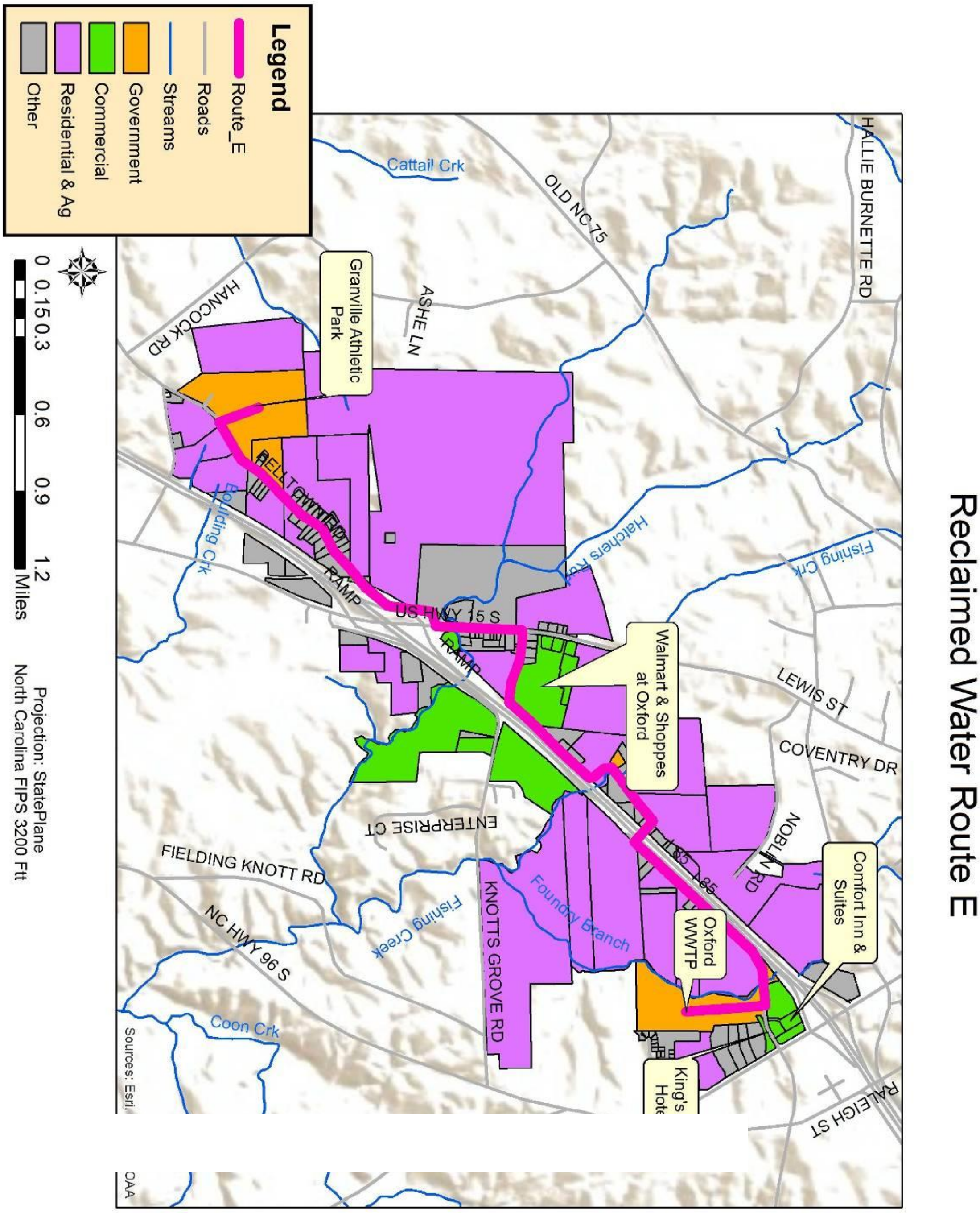


Figure 32: Reclaimed water pipe route E as found in the Reclaimed Water System Study (McGill 2010). Land parcels within 1000 feet are identified and classified.

D. Bayesian network model

a. Questionnaire for conditional probability table

Study on Bayesian network Conditional Probability Table (CPT)

My name is Xiangjun Li, and I`m a second year graduate student at Nicholas School of Environment at Duke University. My master of Environmental Management project is to project several reclaimed water usage scenarios, and estimate the environmental impacts on Fishing Creek, the receiving water, using a Bayesian Network model. When establishing a conceptual Bayesian model, nodes and variables are chosen by experts. Therefore, this questionnaire is aimed to create a CPT by interviewing experts in this field.

The city of Oxford`s Waste Water Treatment Plant (WWTP) treats a combination of industrial, commercial and domestic wastewater, with the process of mechanical screening, anaerobic and aerobic zones, and UV disinfection. An average rate of 1.1 million gallon per day (MGD) of treated water discharges into Fishing Creek. A proposed water reuse plan was developed in Granville County for reclaimed water with applications including irrigation and industrial use. The remaining treated water will be discharged into Fishing Creek. The Bayesian model will inform County commissioners as to how much treated wastewater discharge can/should be used as reclaimed water, while maintaining stream health.

Directions: Each question will consist of a table that posits a set of variables with different scenarios. **You may skip any and all questions for which you have no expertise.** The table should be filled out with probabilities based on your knowledge and expertise. Please feel free to include any notes or comments on any question that you feel would help me to better my model. The probabilities in each Row (*not column*), must add up to equal 1.0; see example:

Table 1. Example of simple CPT.

If Zinc concentration is …	Fish richness will be...	
	good	Poor
High	0.1	0.9
Low	0.7	0.3

The first row of the CPT indicates that if the Zinc concentration is high, then there is a 0.1 (10%) chance that fish richness will be good, and a 0.9 chance that the fish richness is poor. In other words, if 100 stream samples are taken having high Zinc concentration, then 10 samples are likely to have good fish richness, but 90 samples might have poor richness.

Your responses are confidential and will only be used in the creation and refinement of this model. Thanks for your participation.

If you have any questions, please contact me at xiangjun.li@duke.edu. Also you are welcome to forward this questionnaire to anyone who has related academic background. Because this questionnaire is part of my master`s project, **please complete it no later than Mar.14th, 2015**.

Thanks so much for your generous help.

Current stream ecosystem statement:

Data that I have collected (2006 and 2012) shows that the NCIBI ratings[1] are excellent, and the total habitat scores are both above 90/100. 100% of the visible landuse near this site is forested/ wetland. Figure 1 to 3 will provide a basic background of Fishing Creek effluent site.

[1] NCIBI: North Carolina Index of Biological Integrity. The NCIBI method was developed for assessing a stream`s biological integrity by examining the structure and health of its fish community, which incorporates information about species richness and composition, pollution indicator, trophic composition, fish abundance, and fish condition.

Figure 1. Effluent discharge site. Treated water discharges from pipes and passes the rocks before flows to Fishing Creek.

Figure 2. Downstream of effluent discharge site


Figure 3. 3.5 miles downstream of effluent discharge site (SR1643, data collected)

General question:

1. What is your expertise? (E.g. waste water, stream ecology, fish, etc.)
   ____

Conditional Probability Table (CPT)

2. The effect of **treated water/downstream flow ratio** on **D.O. (dissolved oxygen):**

Downstream flow= treated water effluent + upstream natural flow

Currently, there is no Fishing Creek stream flow data. However, it has the 7Q10[2] which is 0.05cfs (0.04MGD).

Therefore, the maximum value is estimated to be 1.1MGD / (1.1+0.04) MGD= 0.96

Do you have any comments about the average or peak flow? ______________________

High _____>0.25_______ Moderate ___0.25-0.05________ Low _____<0.05______

If Treated water/downstream flow is	D.O. will be … (mg/L)		
	Good (8-14)	Fair (5-8)	Poor (<5)
High (>0.25)	0.7	0.2	0.1
Moderate (0.25-0.05)	0.6	0.3	0.1
Low (<0.05)	0.4	0.3	0.3

3. The effect of **treated water/downstream flow ratio** on **Zinc concentration (ug/L):**

	Zinc concentration will be … (ug/L)

[2] 7Q10: the lowest 7-day average flow that occurs once every 10 years.

If Treated water/downstream flow is	Low (0-30)	Moderate (30-50)	High (>50)
High (>0.25)	0.3	0.3	0.4
Moderate (0.25-0.05)	0.2	0.5	0.3
Low (<0.05)	0.6	0.2	0.2

4. The effect of **treated water/downstream flow ratio** on **algae coverage:**

If Treated water/downstream flow is	Algae coverage will be … (g/m^2)		
	Low	Moderate	High
High (>0.25)	0.5	0.3	0.2
Moderate (0.25-0.05)	0.3	0.4	0.3
Low (<0.05)	0.4	0.3	0.3

5. The effect of **Zinc concentration and D.O.** on **Fish abundance**:

E.g. If dissolved oxygen concentration is good (>8mg/L), and Zinc concentration is low (<30ug/L), then what is the percentage probability that fish abundance will be high (# of fish between 300-224)?

If D.O. is… (mg/L)	If Zinc is… (ug/L)	Fish abundance will be …		
		High (224-723)	Moderate (150-224)	Low (<150)
Good (8-14)	Low (0-30)	0.8	0.2	0.
Good (8-14)	Moderate (30-50)	0.75	0.2	0.05
Good (8-14)	High (>50)	0.5	0.3	0.2
Fair (5-8)	Low (0-30)	0.75	0.2	0.05
Fair (5-8)	Moderate (30-50)	0.6	0.3	0.1
Fair (5-8)	High (>50)	0.5	0.3	0.2
Poor (<5)	Low (0-30)	0.4	0.4	0.2
Poor (<5)	Moderate (30-50)	0.25	0.4	0.35
Poor (<5)	High (>50)	0.2	0.3	0.5

6. The effect of **Zinc concentration** and **D.O.** on **Fish species richness:**

If D.O. is… (mg/L)	If Zinc is… (ug/L)	Fish species richness will be …		
		High (15-30)	Moderate (10-15)	Low (<10)
Good (8-14)	Low (0-30)	0.8	0.15	0.05
Good (8-14)	Moderate (30-50)	0.7	0.2	0.1

Good (8-14)	High (>50)	0.6	0.3	0.1
Fair (5-8)	Low (0-30)	0.7	0.15	0.15
Fair (5-8)	Moderate (30-50)	0.55	0.3	0.15
Fair (5-8)	High (>50)	0.45	0.35	0.2
Poor (<5)	Low (0-30)	0.4	0.4	0.2
Poor (<5)	Moderate (30-50)	0.25	0.4	0.35
Poor (<5)	High (>50)	0.15	0.3	0.55

7. The effect of **fish abundance** and **fish species richness** on **NCIBI**:

If fish abundance is…	If fish species richness is	NCIBI will be…			
		Good (46-60)	Good-fair (40-44)	Fair (34-38)	Poor (<34)
High (224-300)	High (15-30)	0.8	0.15	0.05	0
High (224-300)	Moderate (10-15)	0.7	0.25	0.05	0
High (224-300)	Low (<10)	0.3	0.4	0.2	0.1
Moderate (150-224)	High (15-30)	0.7	0.15	0.1	0.05
Moderate (150-224)	Moderate (10-15)	0.5	0.3	0.15	0.05
Moderate (150-224)	Low (<10)	0.25	0.4	0.25	0.1
Low (<150)	High (15-30)	0.5	0.3	0.15	0.05
Low (<150)	Moderate (10-15)	0.2	0.4	0.3	0.1
Low (<150)	Low (<10)	0.1	0.2	0.4	0.3

8. The effect of **D.O. concentration and Zinc concentration** on **Benthos abundance**:

Benthos = Insecta, Crustacea, Mollusca and other

There is currently no scale for Benthos abundance. How would you scale the Benthos abundance?

High:___ >300 m^{-2}_____; Moderate:____ _100-300 m^{-2}_______ Low _____<100 m^{-2}_______

Use your scale to fill in this table.

If D.O. is… (mg/L)	If Zinc is… (ug/L)	Benthos abundance will be …		
		High	Moderate	Low
Good (8-14)	Low (0-30)	0.9	0.1	0
Good (8-14)	Moderate (30-50)	0.9	0.1	0
Good (8-14)	High (>50)	0.8	0.2	0

Fair (5-8)	Low (0-30)	0.7	0.2	0.1
Fair (5-8)	Moderate (30-50)	0.6	0.3	0.1
Fair (5-8)	High (>50)	0.5	0.3	0.2
Poor (<5)	Low (0-30)	0.3	0.5	0.2
Poor (<5)	Moderate (30-50)	0.2	0.6	0.2
Poor (<5)	High (>50)	0.1	0.4	0.5

9. The effect of **D.O. concentration** and **Zinc concentration** on **Benthos species richness:**
How would you scale the benthos richness?
High >30 genera _____ Moderate____10-30 genera ______ Low___<10 genera_
Use your scale to fill in this table.

If D.O. is… (mg/L)	If Zinc is… (ug/L)	Benthos species richness will be …		
		High	Moderate	Low
Good (8-12)	Low (0-30)	1	0	0
Good (8-12)	Moderate (30-50)	0.9	0.1	0
Good (8-12)	High (>50)	0.8	0.2	0
Fair (5-8)	Low (0-30)	0.7	0.2	0.1
Fair (5-8)	Moderate (30-50)	0.6	0.3	0.1
Fair (5-8)	High (>50)	0.5	0.3	0.2
Poor (<5)	Low (0-30)	0.3	0.5	0.2
Poor (<5)	Moderate (30-50)	0.3	0.5	0.2
Poor (<5)	High (>50)	0.3	0.4	0.3

10. The effect of **algae coverage** on **Benthos abundance**:

If algae coverage is	Benthos abundance will be …		
	High	Moderate	Low
High (>0.6)	0.4	0.3	0.3
Moderate (0.4-0.6)	0.3	0.4	0.3
Low (<4)	0.3	0.3	0.4

11. The effect of **Benthos species richness** and **Benthos abundance** on Bioclassification:
Bioclassification is a scale that categories community composition and diversity to determine a classification for a stream site.

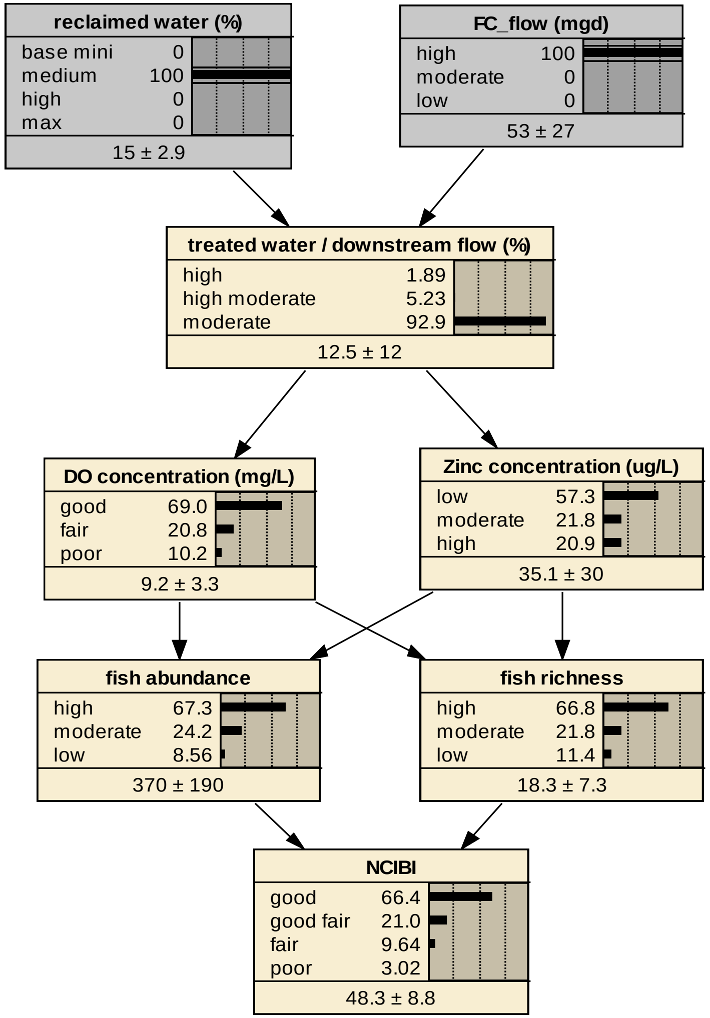
If benthos richness is …	If benthos abundance is …	Bioclassification will be …		
		Good	Fair	Poor
High	High	0.8	0.1	0.1
High	Moderate	0.7	0.2	0.1
High	Low	0.6	0.3	0.1

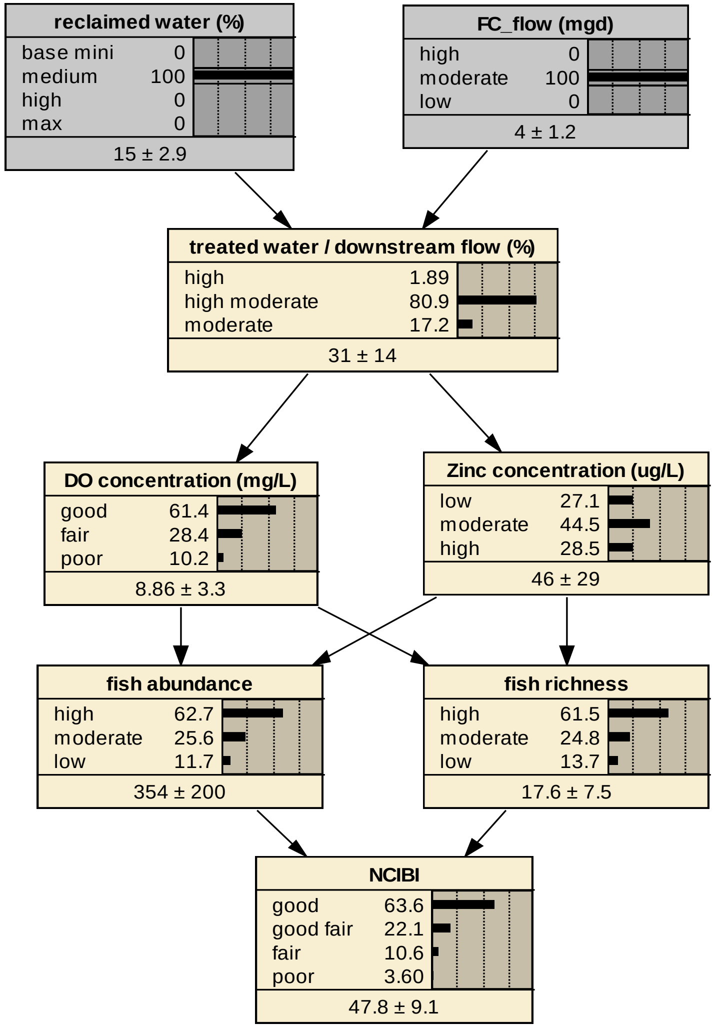
Moderate	High	0.7	0.2	0.1
Moderate	Moderate	0.6	0.3	0.1
Moderate	Low	0.5	0.3	0.2
Low	High	0.5	0.3	0.2
Low	Moderate	0.3	0.4	0.3
Low	Low	0.1	0.3	0.6

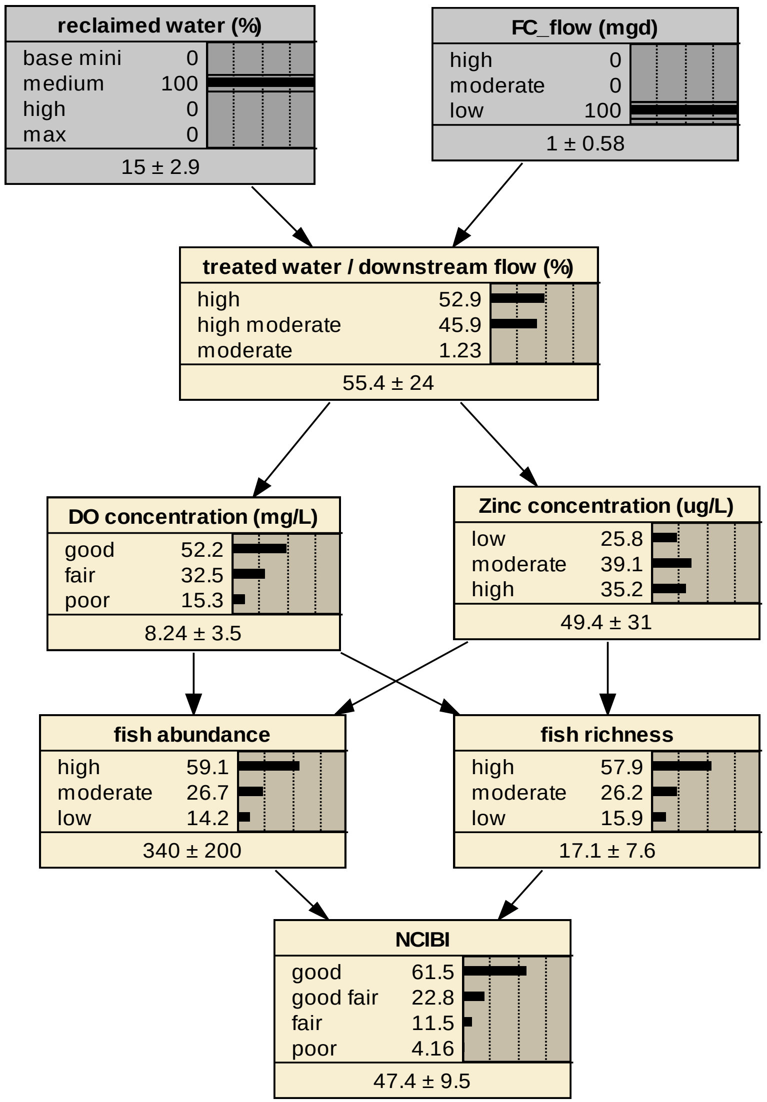
12. If you have any other comments:____

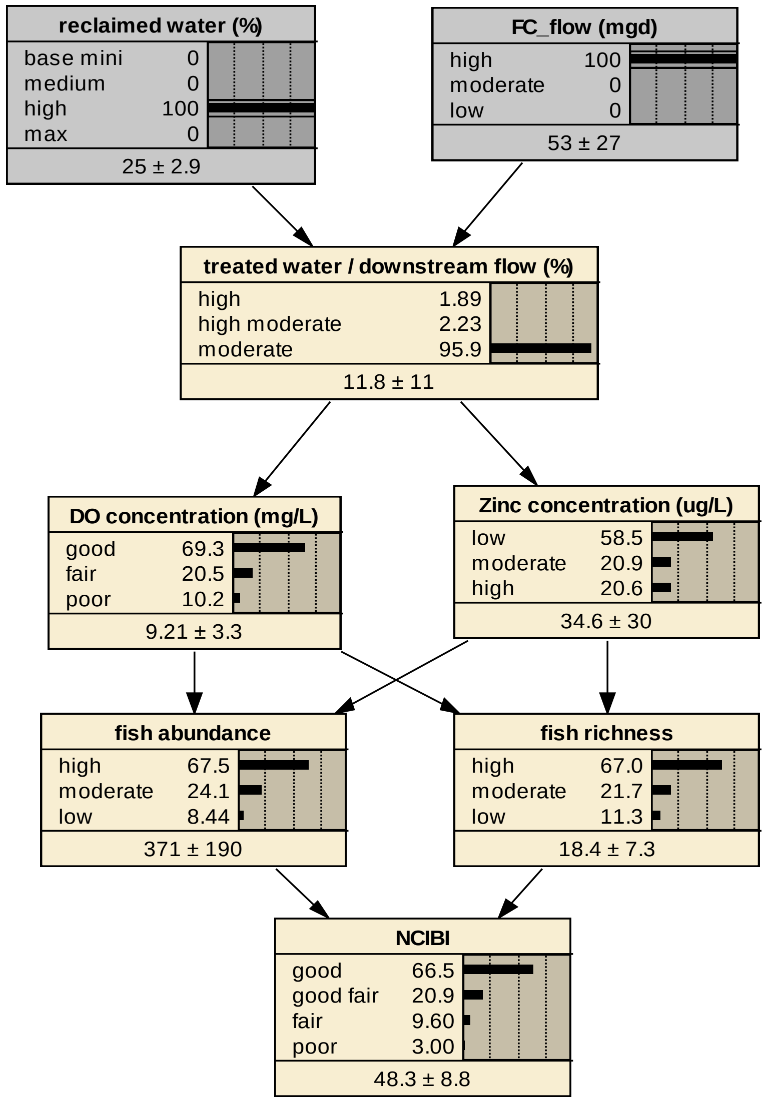
Thanks for your participation. **Please complete it no later than Mar.14th, 2015**.

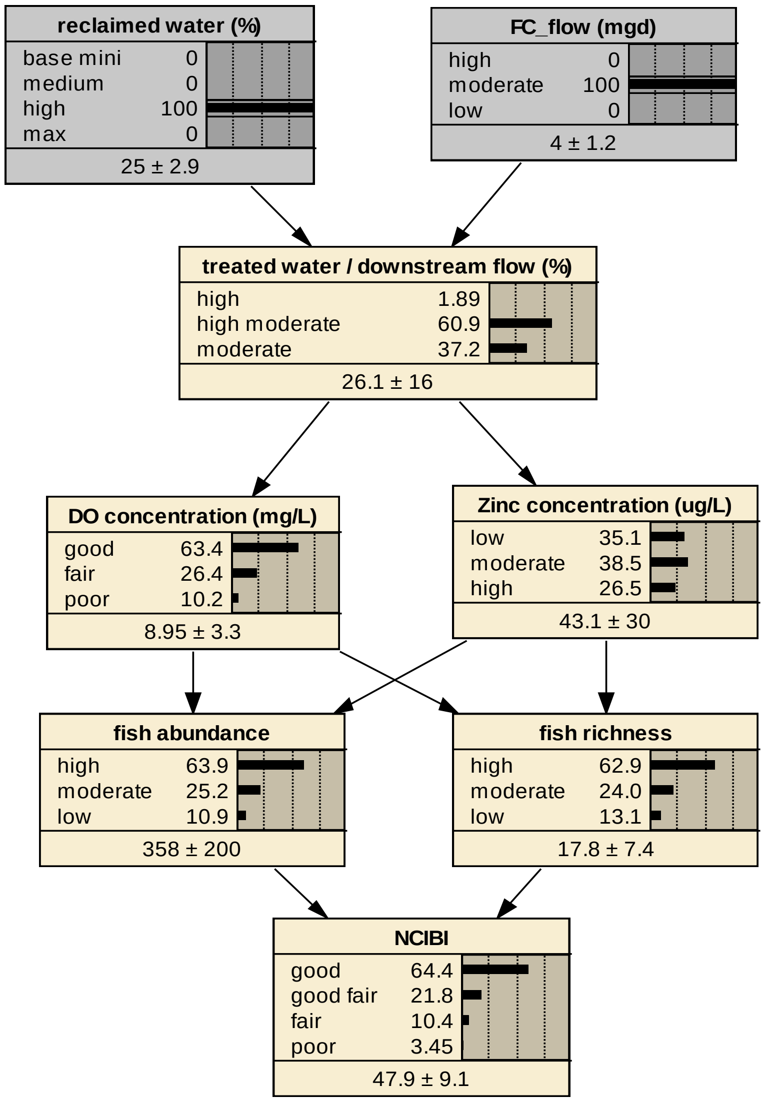
b. Application of Bayesian network model

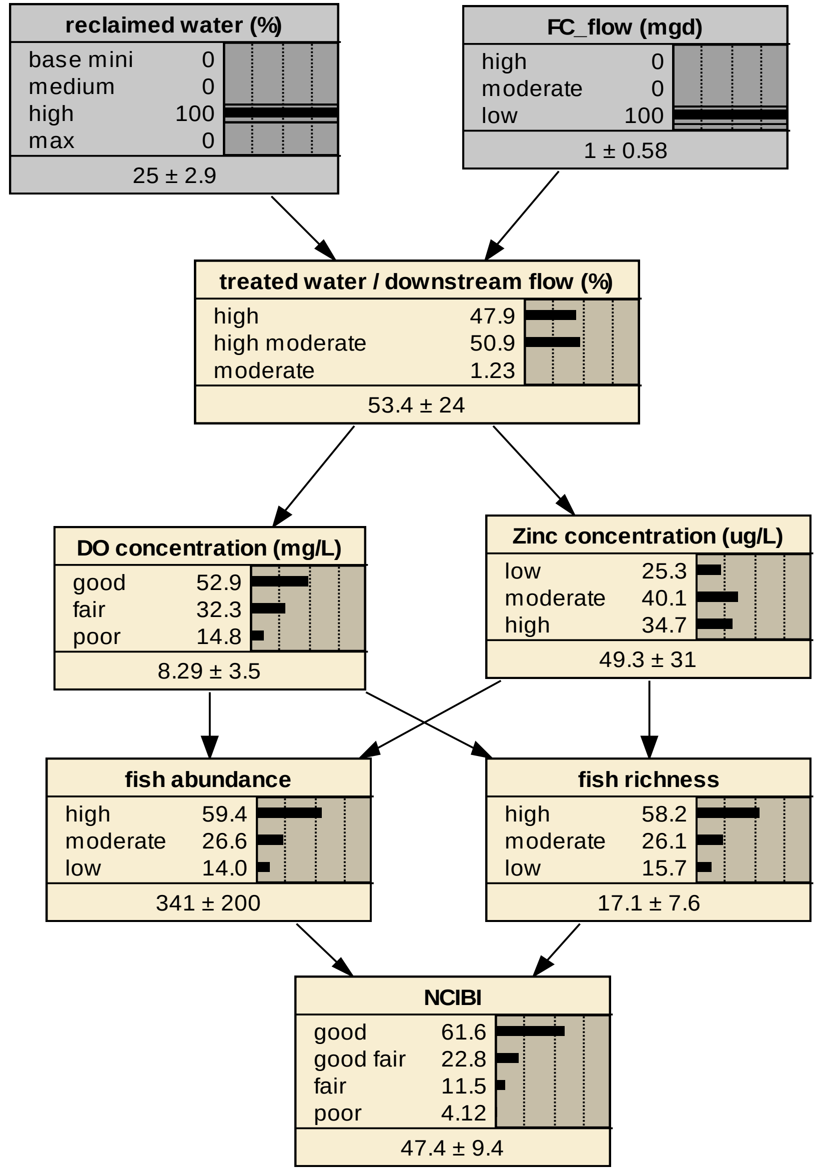


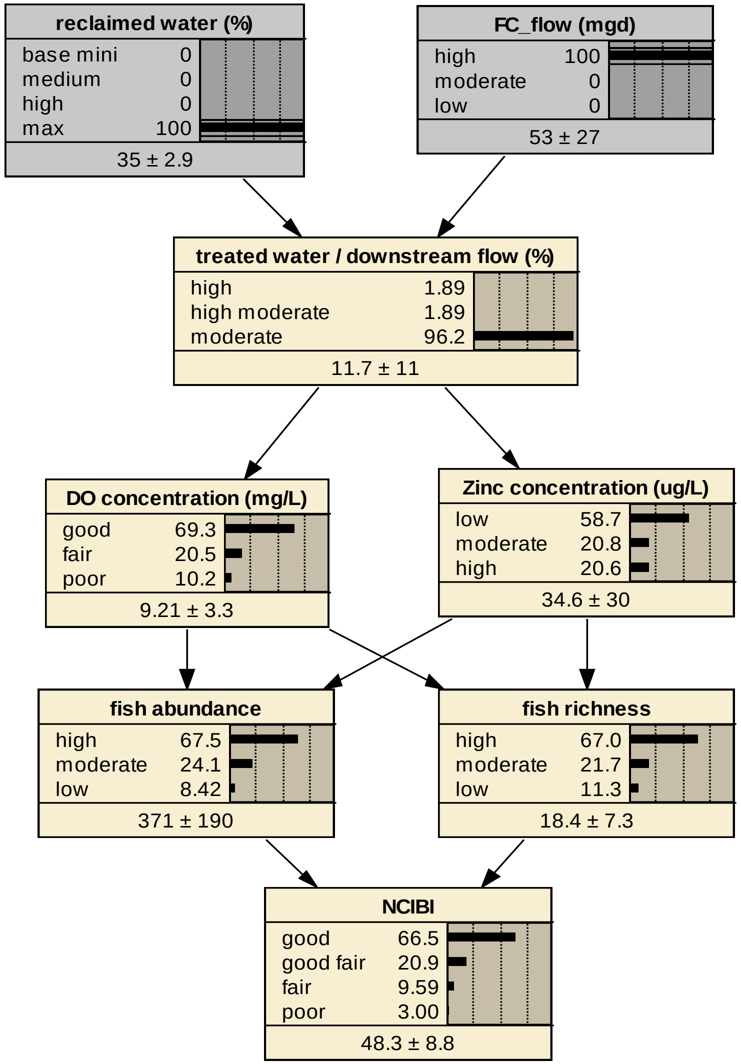



reclaimed water (%)
base mini 0
medium 100
high 0
max 0
15 ± 2.9
FC_flow (mgd)
high 0
moderate 0
low 100
1 ± 0.58
treated water / downstream flow (%)
high 52.9
high moderate 45.9
moderate 1.23
55.4 ± 24
DO concentration (mg/L)
good 52.2
fair 32.5
poor 15.3
8.24 ± 3.5
Zinc concentration (ug/L)
low 25.8
moderate 39.1
high 35.2
49.4 ± 31
fish abundance
high 59.1
moderate 26.7
low 14.2
340 ± 200
fish richness
high 57.9
moderate 26.2
low 15.9
17.1 ± 7.6
NCIBI
good 61.5
good fair 22.8
fair 11.5
poor 4.16
47.4 ± 9.5

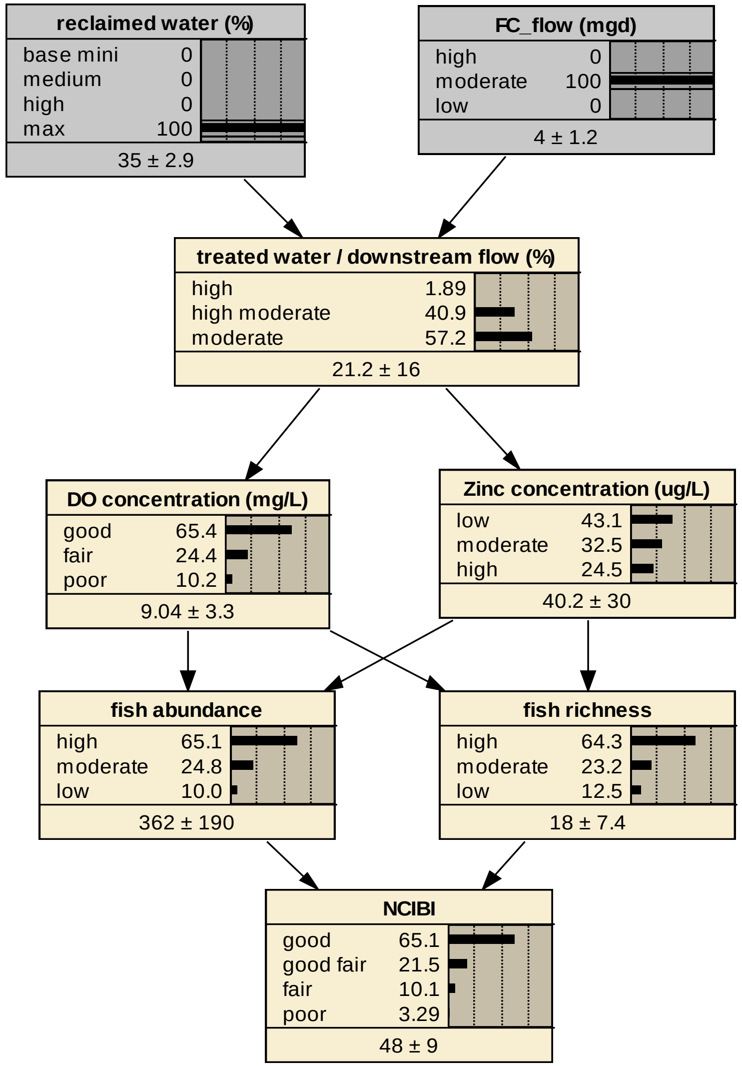

reclaimed water (%)
base mini 0
medium 0
high 100
max 0
25 ± 2.9
FC_flow (mgd)
high 100
moderate 0
low 0
53 ± 27
treated water / downstream flow (%)
high 1.89
high moderate 2.23
moderate 95.9
11.8 ± 11
DO concentration (mg/L)
good 69.3
fair 20.5
poor 10.2
9.21 ± 3.3
Zinc concentration (ug/L)
low 58.5
moderate 20.9
high 20.6
34.6 ± 30
fish abundance
high 67.5
moderate 24.1
low 8.44
371 ± 190
fish richness
high 67.0
moderate 21.7
low 11.3
18.4 ± 7.3
NCIBI
good 66.5
good fair 20.9
fair 9.60
poor 3.00
48.3 ± 8.8


reclaimed water (%)
base mini 0
medium 0
high 100
max 0
25 ± 2.9
FC_flow (mgd)
high 0
moderate 100
low 0
4 ± 1.2
treated water / downstream flow (%)
high 1.89
high moderate 60.9
moderate 37.2
26.1 ± 16
DO concentration (mg/L)
good 63.4
fair 26.4
poor 10.2
8.95 ± 3.3
Zinc concentration (ug/L)
low 35.1
moderate 38.5
high 26.5
43.1 ± 30
fish abundance
high 63.9
moderate 25.2
low 10.9
358 ± 200
fish richness
high 62.9
moderate 24.0
low 13.1
17.8 ± 7.4
NCIBI
good 64.4
good fair 21.8
fair 10.4
poor 3.45
47.9 ± 9.1

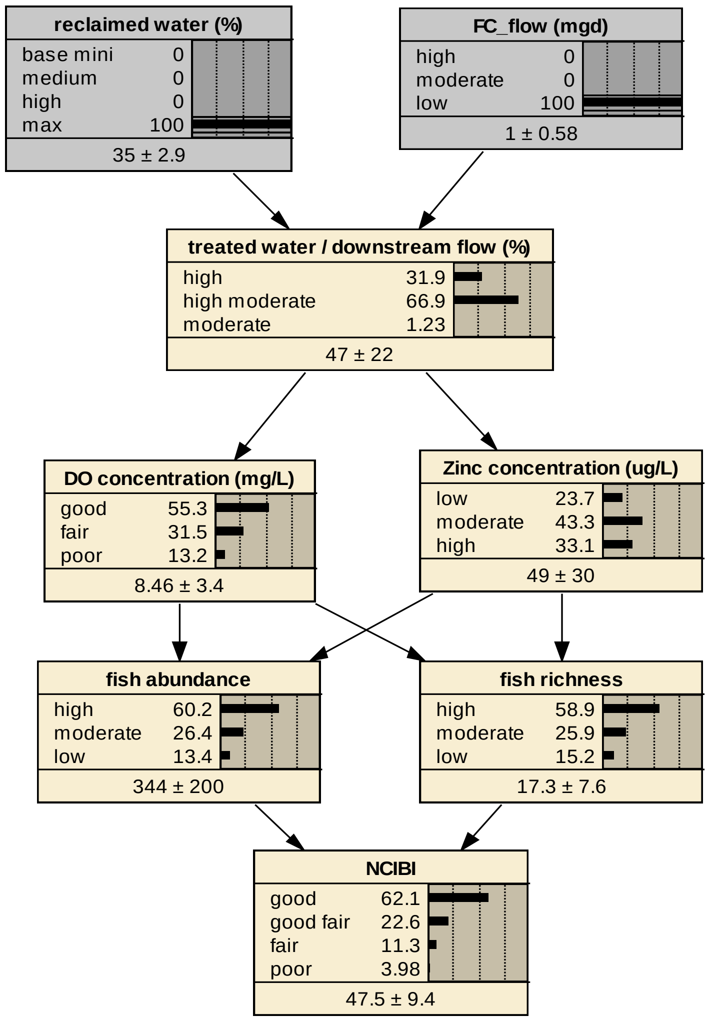

reclaimed water (%)
base mini 0
medium 0
high 100
max 0
25 ± 2.9
FC_flow (mgd)
high 0
moderate 0
low 100
1 ± 0.58
treated water / downstream flow (%)
high 47.9
high moderate 50.9
moderate 1.23
53.4 ± 24
DO concentration (mg/L)
good 52.9
fair 32.3
poor 14.8
8.29 ± 3.5
Zinc concentration (ug/L)
low 25.3
moderate 40.1
high 34.7
49.3 ± 31
fish abundance
high 59.4
moderate 26.6
low 14.0
341 ± 200
fish richness
high 58.2
moderate 26.1
low 15.7
17.1 ± 7.6
NCIBI
good 61.6
good fair 22.8
fair 11.5
poor 4.12
47.4 ± 9.4

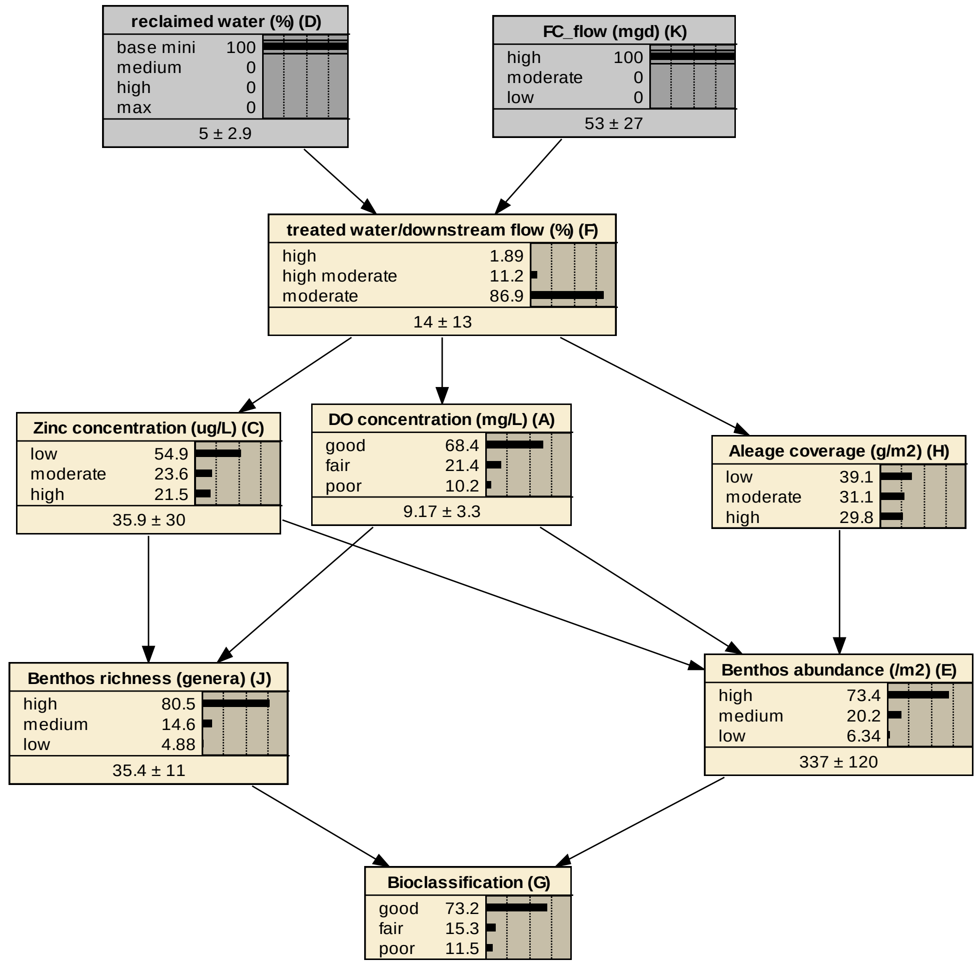


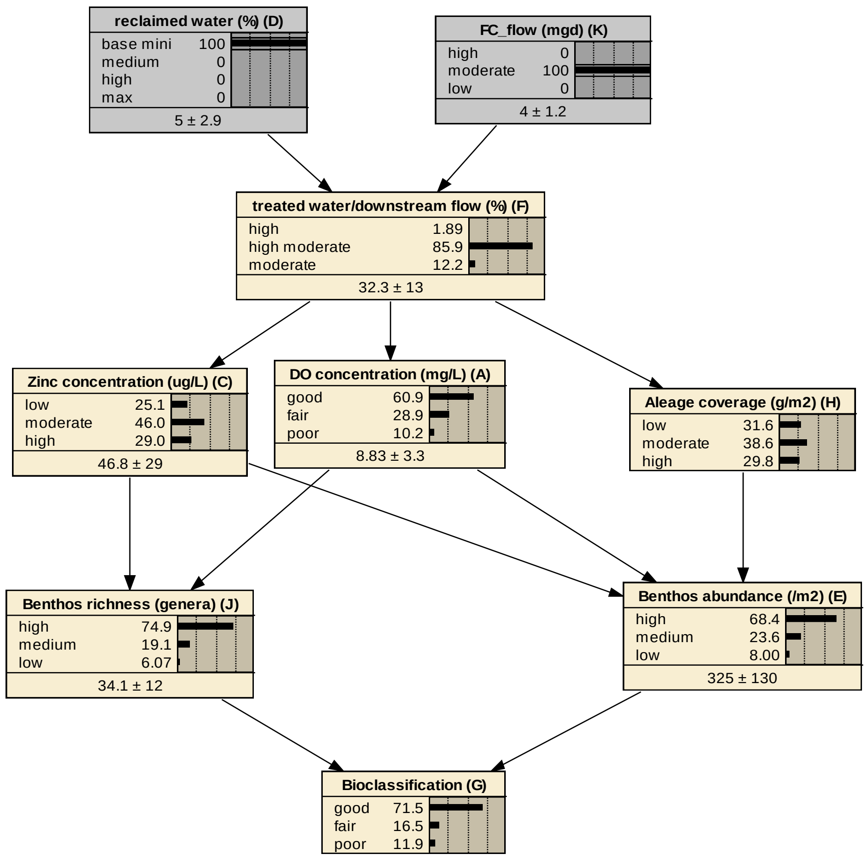
reclaimed water (%)
base mini 0
medium 0
high 0
max 100
35 ± 2.9
FC_flow (mgd)
high 100
moderate 0
low 0
53 ± 27
treated water / downstream flow (%)
high 1.89
high moderate 1.89
moderate 96.2
11.7 ± 11
DO concentration (mg/L)
good 69.3
fair 20.5
poor 10.2
9.21 ± 3.3
Zinc concentration (ug/L)
low 58.7
moderate 20.8
high 20.6
34.6 ± 30
fish abundance
high 67.5
moderate 24.1
low 8.42
371 ± 190
fish richness
high 67.0
moderate 21.7
low 11.3
18.4 ± 7.3
NCIBI
good 66.5
good fair 20.9
fair 9.59
poor 3.00
48.3 ± 8.8



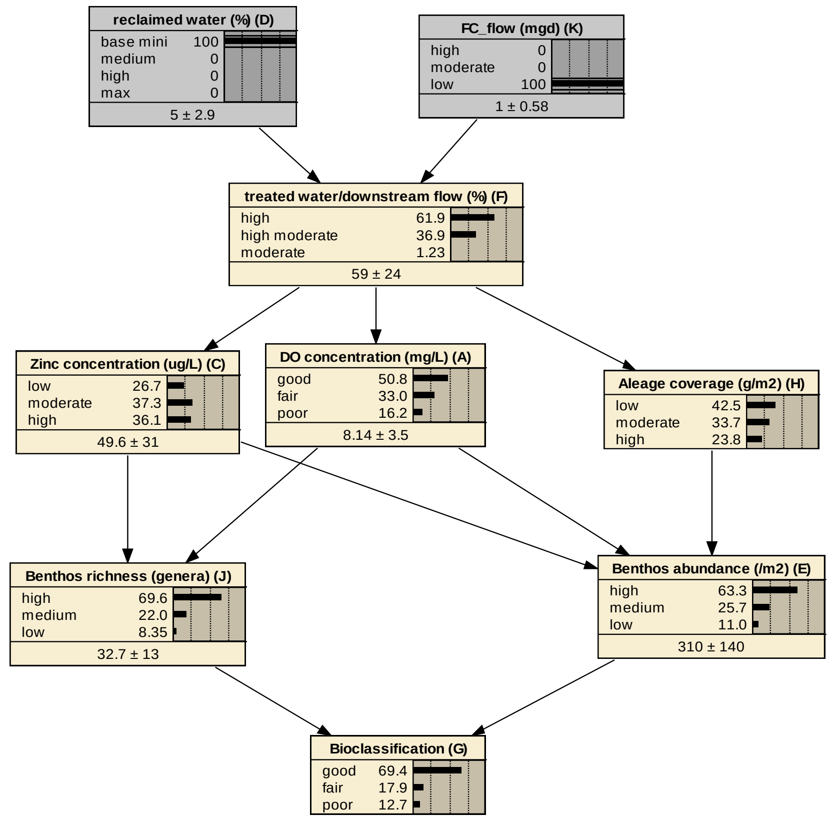
reclaimed water (%)
base mini 0
medium 0
high 0
max 100
35 ± 2.9
FC_flow (mgd)
high 0
moderate 100
low 0
4 ± 1.2
treated water / downstream flow (%)
high 1.89
high moderate 40.9
moderate 57.2
21.2 ± 16
DO concentration (mg/L)
good 65.4
fair 24.4
poor 10.2
9.04 ± 3.3
Zinc concentration (ug/L)
low 43.1
moderate 32.5
high 24.5
40.2 ± 30
fish abundance
high 65.1
moderate 24.8
low 10.0
362 ± 190
fish richness
high 64.3
moderate 23.2
low 12.5
18 ± 7.4
NCIBI
good 65.1
good fair 21.5
fair 10.1
poor 3.29
48 ± 9


reclaimed water (%)
base mini 0
medium 0
high 0
max 100
35 ± 2.9
FC_flow (mgd)
high 0
moderate 0
low 100
1 ± 0.58
treated water / downstream flow (%)
high 31.9
high moderate 66.9
moderate 1.23
47 ± 22
DO concentration (mg/L)
good 55.3
fair 31.5
poor 13.2
8.46 ± 3.4
Zinc concentration (ug/L)
low 23.7
moderate 43.3
high 33.1
49 ± 30
fish abundance
high 60.2
moderate 26.4
low 13.4
344 ± 200
fish richness
high 58.9
moderate 25.9
low 15.2
17.3 ± 7.6
NCIBI
good 62.1
good fair 22.6
fair 11.3
poor 3.98
47.5 ± 9.4

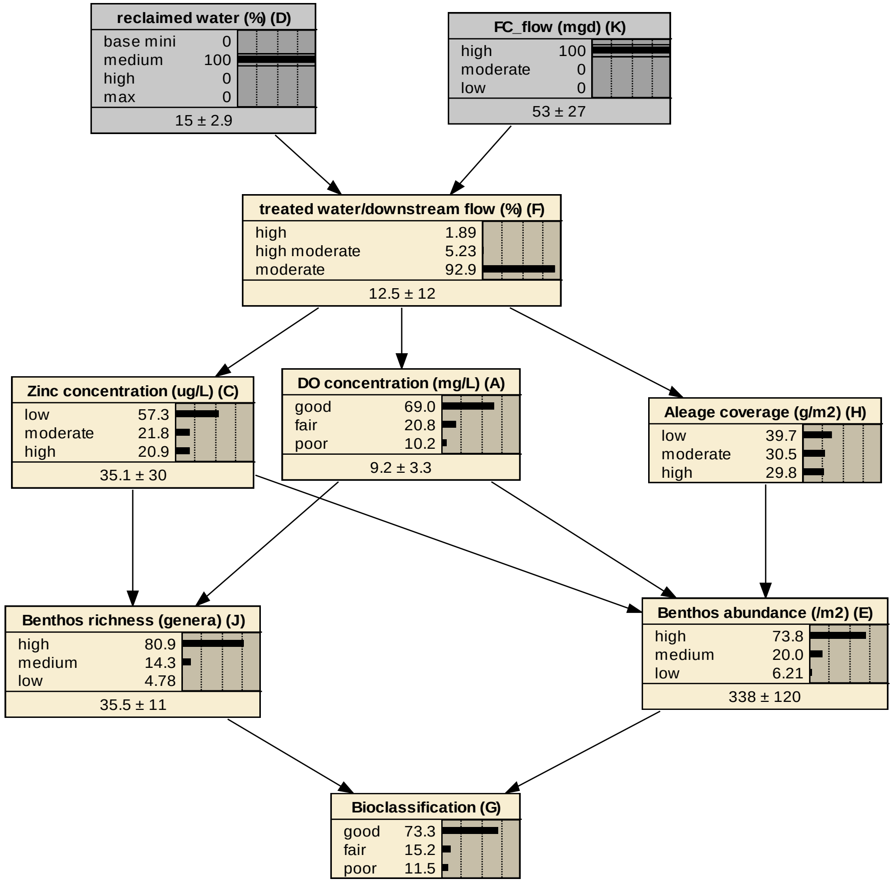

reclaimed water (%) (D)
base mini 100
medium 0
high 0
max 0
5 ± 2.9
FC_flow (mgd) (K)
high 100
moderate 0
low 0
53 ± 27
treated water/downstream flow (%) (F)
high 1.89
high moderate 11.2
moderate 86.9
14 ± 13
Zinc concentration (ug/L) (C)
low 54.9
moderate 23.6
high 21.5
35.9 ± 30
DO concentration (mg/L) (A)
good 68.4
fair 21.4
poor 10.2
9.17 ± 3.3
Aleage coverage (g/m2) (H)
low 39.1
moderate 31.1
high 29.8
Benthos richness (genera) (J)
high 80.5
medium 14.6
low 4.88
35.4 ± 11
Benthos abundance (/m2) (E)
high 73.4
medium 20.2
low 6.34
337 ± 120
Bioclassification (G)
good 73.2
fair 15.3
poor 11.5

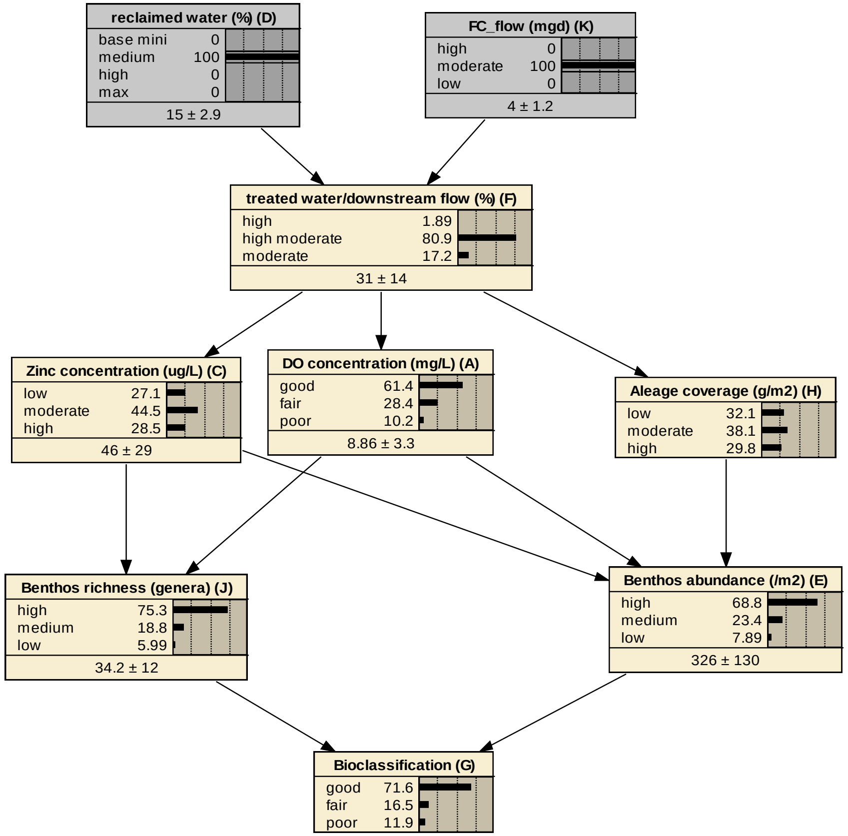


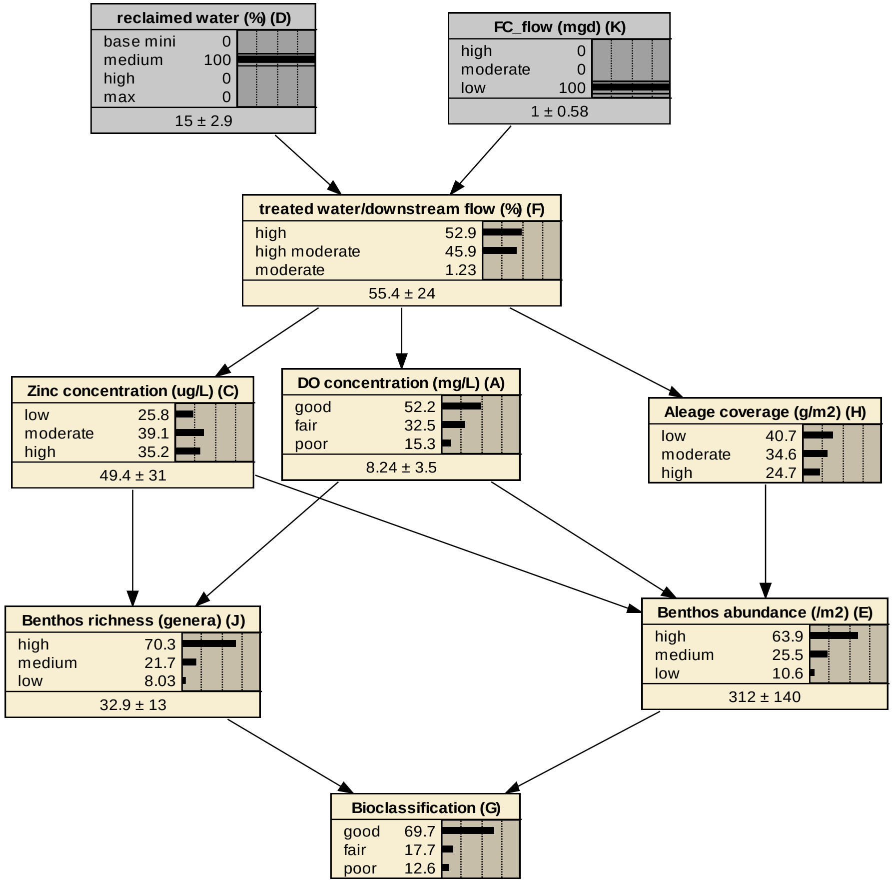
reclaimed water (%) (D)
base mini 100
medium 0
high 0
max 0
5 ± 2.9
FC_flow (mgd) (K)
high 0
moderate 100
low 0
4 ± 1.2
treated water/downstream flow (%) (F)
high 1.89
high moderate 85.9
moderate 12.2
32.3 ± 13
Zinc concentration (ug/L) (C)
low 25.1
moderate 46.0
high 29.0
46.8 ± 29
DO concentration (mg/L) (A)
good 60.9
fair 28.9
poor 10.2
8.83 ± 3.3
Aleage coverage (g/m2) (H)
low 31.6
moderate 38.6
high 29.8
Benthos richness (genera) (J)
high 74.9
medium 19.1
low 6.07
34.1 ± 12
Benthos abundance (/m2) (E)
high 68.4
medium 23.6
low 8.00
325 ± 130
Bioclassification (G)
good 71.5
fair 16.5
poor 11.9

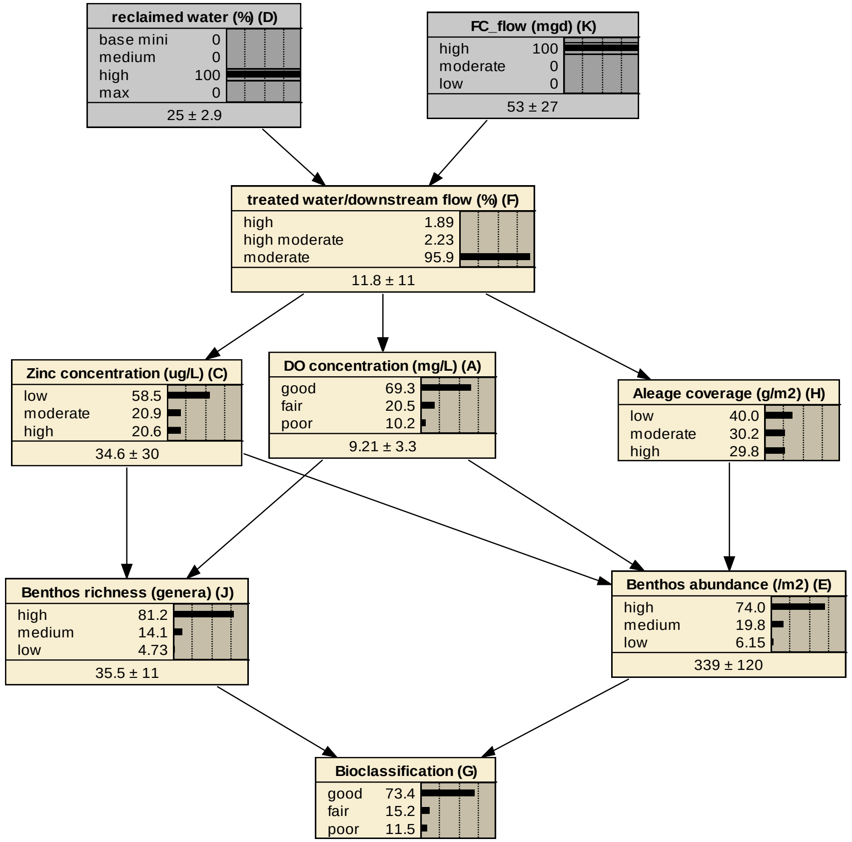


reclaimed water (%) (D)
base mini 100
medium 0
high 0
max 0
5 ± 2.9
FC_flow (mgd) (K)
high 0
moderate 0
low 100
1 ± 0.58
treated water/downstream flow (%) (F)
high 61.9
high moderate 36.9
moderate 1.23
59 ± 24
Zinc concentration (ug/L) (C)
low 26.7
moderate 37.3
high 36.1
49.6 ± 31
DO concentration (mg/L) (A)
good 50.8
fair 33.0
poor 16.2
8.14 ± 3.5
Aleage coverage (g/m2) (H)
low 42.5
moderate 33.7
high 23.8
Benthos richness (genera) (J)
high 69.6
medium 22.0
low 8.35
32.7 ± 13
Benthos abundance (/m2) (E)
high 63.3
medium 25.7
low 11.0
310 ± 140
Bioclassification (G)
good 69.4
fair 17.9
poor 12.7


reclaimed water (%) (D)
base mini 0
medium 100
high 0
max 0
15 ± 2.9
FC_flow (mgd) (K)
high 100
moderate 0
low 0
53 ± 27
treated water/downstream flow (%) (F)
high 1.89
high moderate 5.23
moderate 92.9
12.5 ± 12
Zinc concentration (ug/L) (C)
low 57.3
moderate 21.8
high 20.9
35.1 ± 30
DO concentration (mg/L) (A)
good 69.0
fair 20.8
poor 10.2
9.2 ± 3.3
Aleage coverage (g/m2) (H)
low 39.7
moderate 30.5
high 29.8
Benthos richness (genera) (J)
high 80.9
medium 14.3
low 4.78
35.5 ± 11
Benthos abundance (/m2) (E)
high 73.8
medium 20.0
low 6.21
338 ± 120
Bioclassification (G)
good 73.3
fair 15.2
poor 11.5


reclaimed water (%) (D)
base mini 0
medium 100
high 0
max 0
15 ± 2.9
FC_flow (mgd) (K)
high 0
moderate 100
low 0
4 ± 1.2
treated water/downstream flow (%) (F)
high 1.89
high moderate 80.9
moderate 17.2
31 ± 14
Zinc concentration (ug/L) (C)
low 27.1
moderate 44.5
high 28.5
46 ± 29
DO concentration (mg/L) (A)
good 61.4
fair 28.4
poor 10.2
8.86 ± 3.3
Aleage coverage (g/m2) (H)
low 32.1
moderate 38.1
high 29.8
Benthos richness (genera) (J)
high 75.3
medium 18.8
low 5.99
34.2 ± 12
Benthos abundance (/m2) (E)
high 68.8
medium 23.4
low 7.89
326 ± 130
Bioclassification (G)
good 71.6
fair 16.5
poor 11.9


reclaimed water (%) (D)
base mini 0
medium 100
high 0
max 0
15 ± 2.9
FC_flow (mgd) (K)
high 0
moderate 0
low 100
1 ± 0.58
treated water/downstream flow (%) (F)
high 52.9
high moderate 45.9
moderate 1.23
55.4 ± 24
Zinc concentration (ug/L) (C)
low 25.8
moderate 39.1
high 35.2
49.4 ± 31
DO concentration (mg/L) (A)
good 52.2
fair 32.5
poor 15.3
8.24 ± 3.5
Aleage coverage (g/m2) (H)
low 40.7
moderate 34.6
high 24.7
Benthos richness (genera) (J)
high 70.3
medium 21.7
low 8.03
32.9 ± 13
Benthos abundance (/m2) (E)
high 63.9
medium 25.5
low 10.6
312 ± 140
Bioclassification (G)
good 69.7
fair 17.7
poor 12.6


reclaimed water (%) (D)
base mini 0
medium 0
high 100
max 0
25 ± 2.9
FC_flow (mgd) (K)
high 100
moderate 0
low 0
53 ± 27
treated water/downstream flow (%) (F)
high 1.89
high moderate 2.23
moderate 95.9
11.8 ± 11
Zinc concentration (ug/L) (C)
low 58.5
moderate 20.9
high 20.6
34.6 ± 30
DO concentration (mg/L) (A)
good 69.3
fair 20.5
poor 10.2
9.21 ± 3.3
Aleage coverage (g/m2) (H)
low 40.0
moderate 30.2
high 29.8
Benthos richness (genera) (J)
high 81.2
medium 14.1
low 4.73
35.5 ± 11
Benthos abundance (/m2) (E)
high 74.0
medium 19.8
low 6.15
339 ± 120
Bioclassification (G)
good 73.4
fair 15.2
poor 11.5

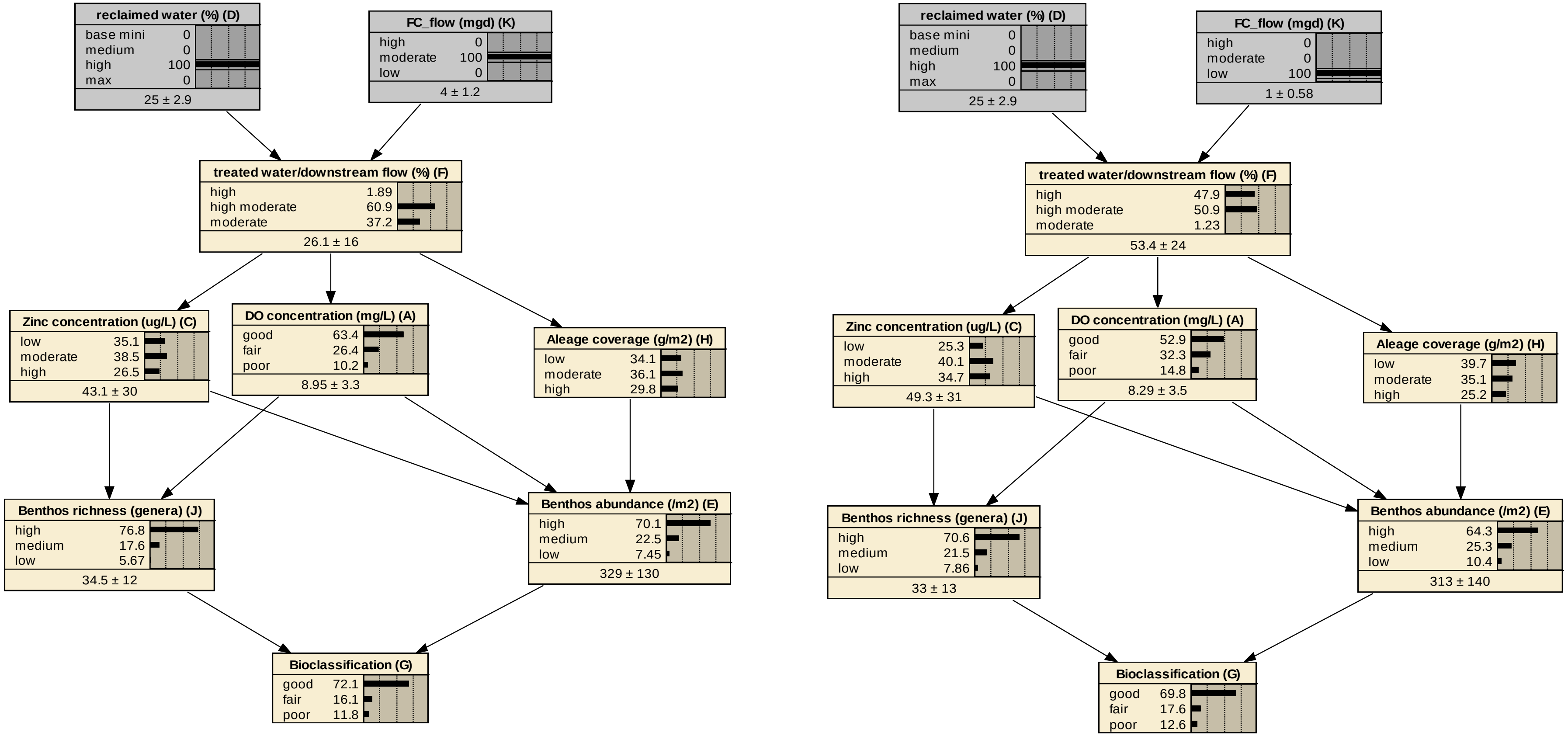


Figure 33-50: Application of Bayesian network model